ECONOMIC IMPACT AND RISK FACTORS ASSOCIATED WITH LUMPY SKIN DISEASE OUTBREAKS IN CATTLE FARMS IN NAKURU COUNTY, KENYA

A thesis submitted in partial fulfilment of requirements for Masters degree of University of Nairobi (Veterinary Epidemiology and Economics)

Samuel Kipruto Kiplagat, BVM

Department of Public Health, Pharmacology and Toxicology

2019

DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

Signature: ____________________ Date: ___________________

Name: Kiplagat Samuel Kipruto – J56/87908/2016

This thesis has been submitted for examination with our approval as University supervisors:

1. Signature:____________________ Date: ___________________

PROF. KITALA PHILIP M (BVM, M.Sc., PhD)

Department of Public Health, Pharmacology and Toxicology

University of Nairobi

2. Signature:____________________ Date: ___________________

DR. ONONO JOSHUA ORUNGO (BVM, M.Sc., MBA., PhD)

Department of Public Health, Pharmacology and Toxicology

University of Nairobi

3. Signature:____________________ Date: ___________________

DR. NICK LYONS (MA, VetMB, MSc, PhD, Dip ECBHM, MRCVS)

The Pirbright Institute, United Kingdom.

DEDICATION

I dedicate this work to my parents for their tireless effort to raise me up and see that I achieve my education goals.

ACKNOWLEDGEMENTS

I thank sincerely my supervisors Prof. P.M. Kitala and Drs J.O. Onono and N.A. Lyons for their tireless effort from the development of the research proposal, fieldwork and writing up of the thesis. Special thanks to Dr. N.A. Lyons for making the fieldwork possible.

I acknowledge the monetary support from Global Challenges Research Fund (GCRF) from Biotechnology and Biological Sciences Research Council (BBSRC) through the Pirbright Institute, United Kingdom.

My gratitude goes to the University of Nairobi administration for admitting me to this course and the CAVs library staff for the assistance accorded to me especially in finding online study resources and plagiarism checks. I cannot forget to thank the farmers of Nakuru County who spared their time to respond to the questionnaires. I also remember in a special way my field assistants, namely, S.K. Kosgei, A.K. Rotich, S.K. Kirwa, K.M Njehia and J.K Kuria together with the Subcounty Veterinary Officers of Nakuru County. My sincere gratitude goes to my classmates in the MVEE course for providing the necessary support and companionship.

I thank the Almighty God for good health and enabling me to finish this study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABREVIATIONS AND ACRONYMS

BVM	Bachelor of Veterinary Medicine
GCRF	Global Challenges Research Fund
BBSRC	Biotechnology and Biological Sciences Research Council
FAO	Food and Agriculture organization of the United Nations
GDP	Gross Domestic Product
GoK	Government of Kenya
KNBS	Kenya National Bureau of Statistics
AgDP	Agricultural Gross Domestic Product
IGAD	Intergovernmental Authority on Development
LPI	Land Policy Initiative
LSD	Lumpy Skin Disease
AU-IBAR	African Union Inter-African Bureau for Animal Resources
EFSA	European Food Safety Authority
IFAT	Immunofluorescence Antibody Test
OIE	World Organization for Animal Health
CFSPH	Centre for Food Security and Public Health
LSDV	Lumpy Skin Disease Virus
pH	potential of Hydrogen
ELISA	Enzyme-linked Immunosorbent Assay
VNT	Virus Neutralization Test
ID Vet	Innovative Diagnostic Veterinary Services
PCR	Polymerase Chain Reaction

DNA	Deoxyribonucleic Acid
SPV	Sheep Pox Virus
KSGP	Kenyan Sheep and Goat Pox
RVF	Rift Valley Fever
BEFV	Bovine Ephemeral Fever Virus
MSD	Merck Sharp and Dohme pharmaceuticals
KEVEVAPI	Kenya Veterinary Vaccines Production Institute
GPV	Goat Pox Virus
CODA-CERVA	Veterinary and Agrochemical Research Centre
GMP	Good Manufacturing Practices
DIVA	Differentiating Infected from Vaccinated Animals
SPPV	Sheep pox Vaccine
GALVmed	Global Alliance for Livestock Veterinary Medicines
SCVO	Subcounty Veterinary Officer
STATA	Data Analysis and Statistical Software
AI	Artificial Insemination
Ksh.	Kenya Shillings
USD	United States of America Dollars
CI	Confidence Interval
EMA	European Medicines Agency

ABSTRACT

Lumpy Skin Disease (LSD) is spreading rapidly to previously disease-free areas causing enormous economic losses. The factors that favour its spread are not extensively studied in the tropics. This study was carried out in Nakuru County, Kenya with the aim of identifying the risk factors of LSD outbreaks and estimating the economic impact of the disease. A retrospective case control study was carried out on 205 farms in order to compare the frequency of risk factors in the case and control farms. A frequency of factor that is greater in cases than in controls is judged as a risk factor. Forty-one and 164 case and control herds were assembled. Data from both case and control herds were collected via questionnaires administered through personal interviews. Data collected included herd sizes, age and sex structures, breeds, source of replacement stock, grazing system and costs (direct and indirect) incurred when LSD outbreaks occurred. The data were analysed using STATA 13® and R 3.3.3 for association tests. A mixed model was used with fixed effects on village and the rest of the variables as random. A univariable and multivariable logistic regression analysis of disease outcome and the risk factors was done and model built by backward fitting using likelihood ratio tests. The economic impact was estimated using the framework and methods suggested by Rushton in 1999 and used by Jemberu *et al.* in 2014 and Molla *et al.* in 2017 in the estimation of economic impact of Foot and Mouth Disease and LSD respectively in Ethiopia. The factors that were significantly associated with LSD outbreaks on univariable analysis included breed, source of replacement stock and herd size. Farms which replaced their herds with cattle from outside the farm were 8.4 times more likely to experience LSD outbreaks compared to farms that replaced from their own herds (p=0.000), exotic breeds were 14.3 times more likely to experience LSD outbreaks

relative to the indigenous breeds (p=0.007), large herds were 3.5 times more likely to experience LSD outbreaks compared to the small herds (p=0.029).. In the multivariable logistic regression model, only breed and source of replacement stock retained their significance indicating that the other variables that lost their significance were confounded by either unmeasured or measured variables. Indigenous breeds of cattle are less susceptible to ectoparasites that include blood feeding arthropods that transmit LSD compared to exotic breeds. Replacement stock from outside the farms could be a source of infection since culling of sick animals is practiced in some farms. Farms with exotic breeds were of cattle were 16.7 times more likely to experience LSD outbreak compared to farms with indigenous breeds of cattle (p=0.01). Farms that sourced their replacement stocks from outside the farm were 8.7 times more likely to experience LSD outbreak compared to farms that did not source their replacement cattle from outside the farms (p<0.001). The direct losses were estimated at an average of Ksh. 2,511 and Ksh. 21,110 per farm keeping indigenous and exotic breeds, respectively. The losses due to milk reduction were estimated at an average of Ksh. 1,890 and Ksh. 11,275 per farm keeping indigenous and exotic breeds of cattle, respectively. Cattle mortalities were estimated at an average of Ksh. 621 and Ksh. 9,835 per farm keeping indigenous and exotic breeds of cattle, respectively. The indirect losses were estimated at an average of Ksh. 4,603 and Ksh. 5,855 per farm keeping indigenous and exotic breeds of cattle. The cost of treatment of secondary infections were estimated at an average of Ksh. 3,715 and Ksh. 5,003 per farm keeping indigenous and exotic breeds of cattle, respectively. The cost of vaccination, whether pre or post LSD, was estimated at average of Ksh. 888 and 852 per farm keeping indigenous and exotic breeds of cattle, respectively. The impact of LSD was higher in farms keeping

exotic breeds than indigenous breeds of cattle. Within the farms keeping exotic breeds, direct losses from LSD had a higher impact with the milk loss being the greatest, followed by mortalities. In the farms with indigenous breeds of cattle, indirect losses had a higher impact with treatment being the greatest source of losses. Based on these estimates, the total losses of LSD for farms keeping indigenous cattle was estimated at Ksh 7,114 and Ksh 26,965 for farms keeping exotic breeds of cattle. Yet, if these farms implemented vaccination as a control strategy against LSD, they would save approximately, Ksh 6,226 and 26,113 for farms keeping indigenous and exotic cattle breeds, respectively. These levels of resources can be reallocated to other management functions within cattle farms. It is recommended that the efficacy of LSD vaccine currently used in Kenya be re-evaluated, farmers are trained on LSD control measures such as vaccination, introduction of cattle examined and certified by the veterinary authorities to be free of notifiable diseases such as LSD and cattle gaining entry into the county for market or pasture and water be vaccinated prior to accessing the county. In conclusion, LSD occurs in Nakuru County and is one of the major causes of morbidity and mortality. Control measures of the disease needs to be refined, especially use of vaccines.

CHAPTER ONE: INTRODUCTION

1.1 Background to the Study

Studies on the epidemiology of infectious diseases such as Lumpy Skin Disease (LSD) include evaluation of risk factors leading to infection by an organism, factors that affect transmission of the organism between susceptible and infectious hosts and factors associated with clinically recognizable disease among infected hosts (Nelson and Williams, 2013). Diseases can be characterized epidemiologically by prevalence, incidence, transmission route and proportions of susceptible populations. This characterization is important for development of a control program that targets specific diseases in populations (Nelson and Williams, 2013). The methods used in quantification of occurrence of diseases in populations include prevalence, and incidence rates (Kruijshaar *et al.*, 2002; Nelson and Williams, 2013) and different mortality measures (Kruijshaar *et al.*, 2002).

Lumpy skin disease (LSD) is a generalized skin disease, which is caused by a poxvirus in the family Poxviridae and the genus capripoxvirus (Ahmed and Zaher, 2008; Gari *et al.*, 2011). The disease typically shows skin nodules of 2 to 5 cm in diameter, lymphadenopathy and fever (Magori-Cohen *et al.*, 2012). The primary hosts of Lumpy Skin Disease are mostly cattle and occasionally in the buffalo (Sharawi and Abd El-Rahim, 2011; El-Tholoth and El-Kenawy, 2016).

The disease is transmitted majorly mechanically by biting and blood feeding arthropods (OIE, 2010; Tuppurainen and Oura, 2012). Therefore, control by quarantine and movement control is not very effective (Coetzer, 2004). The disease outbreak is seasonal depending on abundance of suitable vectors. Mechanical transmission of the virus may be reduced by efficient vector control, but this may be impractical or very costly. Largescale use of insecticides is also not recommended due to environmental pollution. Acts that limit the breeding sites of vectors such as stagnant water, manure and sludge is recommended (Tuppurainen and Golan, 2016). The first case should be detected early enough, followed by a quick and extensive vaccination campaign for a successful control and eradication of LSD (OIE, 2017).

The morbidity of LSD is variable within and between herds. It has been argued that it depends on the status of immunity of the host (host susceptibility) and how abundant the mechanical arthropod vectors are in an environment. The estimated morbidity in a herd normally ranges from 5% to 45%, with a mortality of between 1 to 10%, with higher mortality attributed to secondary infections (OIE, 2010; 2013). Furthermore, a mortality as high as 75 - 85% have been reported (CFSPH, 2011). A localised outbreak of the disease occurred in Kenya in 1957 within the Rift Valley province, around Lake Nakuru (Burdin, 1959; MacOwan, 1959; Davies, 1982). Kenya Sheep and Goat pox Virus (SGPV) was found to have infected the sheep in the farm of first LSD outbreak occurrence. It is believed that this first LSD occurrence was from Kenya SGPV that had a changed host adaptation for cattle. This is because the DNA of the viruses were found to be alike on restriction endonuclease analysis (Davies, 1991). After the first outbreak in 1957, LSD epidemics have occurred irregularly in various parts of Kenya (AU-IBAR, 2013) with low level of reporting. Some media houses have reported suspected LSD cases in Nakuru (Standard Group PLC, 2015), Kiambu (Hivisasa, 2015), Muranga (Standard PLC, 2018), Baringo (Standard Group PLC, 2019a&b), Bungoma (Knowledge Bylanes Kenya, 2017) and Uasin Gishu (Hivisasa, 2018) counties. Coakley and Capstick (1961) developed a vaccine from

Kedong strain of LSDV and its use in vaccination is thought to have prevented a possible spread of the disease epidemic in 1968. Owing to how the disease behaved in Kenya, it was hypothesized that the virus was particular to high altitude and indigenous trees covered areas, like the Mau Forest (Davies, 1982). The isolated strains of LSD virus from the first outbreak in 1957 and subsequent years have been found to be serologically the same. Additionally, the South African Neethling and the West African strains are also related. Therefore, they can only be differentiated by use of indirect Fluorescent Antibody Test (FAT) (Davies, 1982).

During the first LSD outbreak of 1957, the morbidity of the disease in Nakuru was 1-2% (Ayres-Smith, 1960). Consequently, the epidemic spread of LSD within Kenya is thought to have caused a considerable economic loss to the farming community and the general economy (MacOwan, 1959) but this loss was not quantified. Although sporadic outbreaks of LSD have continued to occur within the cattle farming systems in Kenya, no studies have to date been conducted to determine the predictors of the disease outbreaks in cattle herds and its subsequent economic cost.

1.2 Objectives of study

1.2.1 Broad objective

To determine the risk factors and economic implications of lumpy skin disease outbreak in cattle production systems in Nakuru County, Kenya.

1.2.2 Specific Objectives

i. To determine the farm-level risk factors of Lumpy skin disease in Nakuru County.

ii. To estimate economic impact of Lumpy Skin Disease outbreak in affected cattle herds in cattle farms.

CHAPTER TWO: LITERATURE REVIEW

2.1 Epidemiology of Lumpy Skin Disease

2.1.1 Aetiology of Lumpy Skin Disease

Lumpy skin disease (LSD) is a generalized viral skin disease. It is caused by a poxvirus in the family Poxviridae and the genus capripoxvirus (Ahmed and Zaher, 2008; Gari *et al.*, 2011).

2.1.2 Animal species affected by Lumpy Skin Disease

The primary hosts of Lumpy Skin Disease are cattle mostly and the buffalo occasionally (Sharawi and Abd El-Rahim, 2011; El-Tholoth and El-Kenawy, 2016).

2.1.3 Occurrence and distribution

The first description of the disease was in Zambia in 1929. In Kenya, it was described in 1957 (MacOwan, 1959). Lumpy Skin Disease was reported in a sheep and cattle mixed farm in Nakuru. The disease is thought to have been introduced by indigenous sheep that was infected with sheep pox virus. The lambs in the farm started showing clinical signs of sheep pox. The calves followed showing a similar condition (Burdin, 1959; African Union Inter-African Bureau for Animal Resources, AU-IBAR, 2013). The calves are thought to have been cross-infected by the virus from the sheep and goats (AU-IBAR, 2013).

Lumpy Skin Disease is a transboundary disease that occurred commonly in most African countries and sporadically in the Middle East. However, since 2012, the disease has been observed to be spreading from the Middle East into Europe (Food and Agriculture Organization of the United Nations, FAO, 2015; European Food Safety Authority, EFSA, 2017).

2.1.4 Clinical signs of Lumpy Skin Disease

The LSDV causes a systemic disease that can be acute or sub-acute. The typical symptoms can be mild to severe and include fever, dermal and mucosal nodules (Tuppurainen, 2005; Centre for Food Security and Public Health, CFSPH, 2008). Nodules are also found in the internal organs, lymphadenitis, oedema and occasionally death (Tuppurainen, 2005) are reported. Raised, circular, firm, coalescing nodules on the skin are common and cores of necrotic material called "sit-fasts".

The nodules vary in size from 1 cm to 7 cm in diameter mostly found on the genitalia, perineum, udder, legs, neck, and head. Sometimes the extension into the musculature underneath forms a nidus for fly infestations and secondary bacterial infections (CFSPH, 2008; CFSPH, 2011; Tuppurainen and Oura, 2012). The nodules involve the musculature are frequently painful (OIE, 2010). Regional lymph nodes become up to ten times enlarged, oedematous, congested and have pyaemic foci and cellulitis (Salib and Osman, 2011). High mortalities are usually associated with secondary bacterial infections on the skin and pneumonia (OIE, 2013).

Extensive generalization in animals may cause lameness and subsequent reluctance to move. Prolonged fever may cause abortion (Ocaido *et al.*, 2008).

2.1.5 Transmission and pathogenesis of Lumpy Skin Disease

Biting and blood feeding arthropods are thought to primarily transmit LSDV mechanically (OIE, 2010; Tuppurainen and Oura, 2012). It is thought so because of the disease outbreaks are seasonal, mostly occurring in warm and rainy conditions that coincide with arthropod high densities (Sprygin *et al.*, 2019). Hard ticks (*B. decoloratus, R. appendiculatus* and *A. hebraeum*) could be involved in the transmission of LSDV

(Lubinga *et al.*, 2013, 2014; Tuppurainen *et al.*, 2013a, b, 2014a). *Tabanidae, Glossina* and *Culicoides* spp. are implicated to transmit LSD because of their presence in the areas where there has been continuing active disease (FAO,1991). *Stomoxys calcitrans* experimentally has mechanically transmitted capripoxvirus to naive sheep and goats. (Kitching and Mellor, 1986; Mellor *et al.*, 1987). The fly is thought to transmit LSDV in cattle through the same mechanism (Baldacchino *et al.*, 2013).

The disease can also be transmitted through direct contact between infected and naive animals. However, this route has been found to be ineffective for spread of the disease (Weiss, 1968; Carn and Kitching, 1995; CFSPH, 2008).

The sources of infection include cutaneous lesions and crusts, blood, secretions of the nose and eyes, saliva, milk and semen (Irons *et al.*, 2005). These nodules are commonly present on the nasal, lachrymal, buccal, rectal genital and udder mucous membranes (OIE, 2013). Subclinical infection is common with clinical signs of the disease observed in about half of the animals infected (Tuppurainen and Oura, 2012). The skin lesions at an acute stage show changes in the histopathology. These include lymphangitis and vasculitis followed by thrombosis and infarction. The result is oedema of the skin as well as necrosis and lymphadenopathy. Initially, serum may exude from the LSD skin nodules. Then as it ages, it develops a typical zone of necrosis that is inverted, greyish pink and conical. The adjoining tissue present with oedema, haemorrhages and congestion. The necrotic cores separate from the adjoining skin to form what is known as ‘sit-fasts’. The necrotic cores lead to secondary bacterial infection. During LSD infection, several virus-encoded factors are produced. The factors are responsible for influencing the pathogenesis (Tuppurainen and Oura, 2012).

2.2 Diagnosis of Lumpy Skin Disease

The recently commercially available diagnostic test kits for LSDV is double antigen ELISA from Innovative Diagnostics®. It has improved sensitivity (>99.7%) compared to Virus Neutralization Test (VNT) (Innovative Diagnostics Vet, 2017). The characteristic clinical signs and differential diagnosis of LSD can also be used to form the tentative diagnosis. Clinical diagnosis can be confirmed in the laboratory using conventional PCR tests (Tuppurainen, 2005; CFSPH, 2008; OIE, 2011; OIE, 2013; OIE, 2017) and virus isolation (OIE, 2017).

2.3 Prevention and control of Lumpy Skin Disease

The LSDV has a potential to spread rapidly and causes significant economic losses. Therefore, the Office International des Epizooties (OIE) includes LSD in the list of notifiable diseases of cattle (Bowden *et al.*, 2008). Farms may practice the isolation of sick animals from the unaffected animals and symptomatic treatment that consist of local dressing of wounds and application of repellent sprays to avoid fly infestations and secondary infections (CFSPH, 2008; Tuppurainen and Oura, 2012). Broad spectrum antibiotics may be administered for infections affecting the skin, lungs and cellulitis (Davies, 1991).

2.3.1 Sanitary prophylaxis

Sanitary prophylaxes include restrictions of importation of livestock, semen, carcasses, skins and hides to help prevent the introduction of LSD into disease-free countries (Thrusfield, 2005) as it has been shown that cutaneous lesions and crusts, blood, secretions of the nose and eyes, saliva, milk and semen are sources of infection (Irons *et al.*, 2005).

Outbreaks may be controlled and eliminated by strict quarantine, restriction of animal movements, isolation and slaughtering of all affected animals, appropriate carcass disposal, washing and disinfection of the buildings and control of insects (CFSPH, 2008; Tuppurainen and Oura, 2012; OIE, 2013). Control and elimination of LSDV is complicated especially in countries where viability of slaughter of all affected and/or in contact with affected animals is low. This is because of the presence of asymptomatic animals shedding the virus (Tuppurainen *et al.,* 2015). These asymptomatic animals can transmit the virus through arthropod vectors (Tuppurainen *et al.,* 2015). Animals affected by CaPV do not become carriers. The infection will be cleared eventually (Tuppurainen *et al.,* 2015). However, LSD virus isolation is possible up to 35 days in cutaneous skin lesions and crusts and PCR can demonstrate nucleic acid of the virus up to 3 months. The semen of some infected bulls have demonstrated the DNA of LSDV up to 5 months post-infection. Additionally, saliva, semen and skin nodules of experimentally infected cattle have demonstrated LSDV for 11, 22 and 33 days respectively. No virus has been isolated from urine or faeces (OIE, 2013).

2.3.2 Medical prophylaxis

Vaccination is the only effective medical control measure (OIE, 2013) which should target the whole affected region with 100% vaccination coverage so as to stop a continued spread of the virus into areas free of the disease (Tuppurainen and Golan, 2016). Lumpy Skin Disease has been successfully vaccinated against by use of homologous live attenuated virus vaccine and heterologous live attenuated virus vaccines. Heterologous vaccines (sheeppox and goatpox vaccines) use in sheep and goat pox disease free countries is not advised (Tuppurainen and Oura, 2012; OIE, 2013) as the level of attenuation essential to safely administer in sheep and goats is lower than that required for cattle. Therefore, the vaccine can become a potential source of infection for the naive sheep and goat herds (Coetzer, 2004). Capripoxvirus strains are homologous, therefore, it has the potential of being used to protect cattle, sheep and goats as a single vaccine strain (Kitching, 2003). Some non-homologous vaccine viruses do not fully protect cattle against LSD. These include the Kenyan sheep pox vaccine strain (Somasundaram, 2011; Ayelet *et al.*, 2013; Tageldin *et al.*, 2014). The Kenyan sheep and goat pox vaccine virus (KSGP) O-240 which was thought to be Sheep Pox Virus (SPV) has been found to be LSDV. The attenuation level of this virus may not be sufficient enough to be safely used in cattle. As such, it causes clinical disease in vaccinated animals. Other strains such as Kedong and Isiolo goat pox strains that can infect cattle, sheep and goats has the potential for use against all capripox diseases as a broad-spectrum vaccine (Tuppurainen *et al*., 2014b).

Lumpy skin disease also occurs in the same geographical areas with other economically and public health important diseases such as Rift Valley fever, *peste des petits ruminants* and sheep pox and goat pox. Therefore, availability of a single multivalent vaccine that can offer protection from all these five diseases is imperative. The South African and Canadian researchers are combining efforts to make this a reality (Boshra *et al*., 2013). This is anticipated to greatly reduce the expensive plans of separately carrying out several vaccinations against these diseases (Boshra *et al*., 2013). Research on recombinant Rift Valley fever virus (RVFV) and bovine ephemeral fever virus (BEFV) with LSDV have been tried. Mice were protected against challenge from virulent RVFV by the recombinant construct of LSDV-RVFV. Cattle were partially protected against the virulent challenge by the LSDV-BEFV recombinant construct. However, specific immune response, both humoral and cellular was elicited for BEFV (Wallace and Viljoen, 2005).

Currently, live attenuated vaccines are the ones available for use. They are recommended for use in endemic countries only, unless otherwise authorized. The two vaccines from MSD Animal Health and Onderstepoort Biological Products were shown to contain LSDV in unpublished research (Tuppurainen and Golan, 2016). The Kenyan vaccine that was believed to be LSDV was found to be Goat Pox Virus (GPV) strain (Omoga, 2018) while the KSGP O-180 and KSGP O-240 vaccines were found to be LSDV (Tuppurainen *et al.*, 2014b).

Scientists at CODA-CERVA, Belgium are currently carrying out independent challenge experiments using all currently used live vaccines and two newly developed inactivated vaccines used in cattle against LSDV. The aim of these yet to be published studies is to evaluate the safety and efficacy of all currently used live vaccines and two newly developed vaccines in the protection of cattle against LSDV (Tuppurainen and Golan, 2016).

The purity of LSDV vaccines is questionable, but can be tested. It may contain endogenous agents and contaminants. This is because the source of primary cells used in their manufacture is small ruminants and the source areas are also endemic with diseases such as bluetongue, foot-and-mouth disease, *peste des petits ruminants*, Rift Valley fever and rabies. Therefore, vaccines used to control LSDV need to be produced under conditions of strict purity testing and Good Manufacturing Process (GMP). Vaccines against LSDV with a Differentiating Infected from Vaccinated Animals (DIVA) factor are not currently available on commercial scale (Tuppurainen and Golan, 2016). Attenuated LSDV field strains or the South-African LSDV Neethling strains are used to manufacture live LSDV vaccines in South Africa. The vaccine containing homologous LSDV is more efficacious than that containing SPV (Ben-Gera *et al.*, 2015). The vaccines do not totally protect every individual animal. Protection at good levels can be achieved by covering 80–90% or more of the herd, followed by annual boosters to maintain protection (Kitching, 2003).

Sheep pox virus and GPV sourced vaccines with demonstrated safety and efficacy against LSDV can be used in cattle. The Middle East previously used SPV vaccines such as Yugoslavian RM65 SPPV and Romanian SPP vaccine. The Yugoslavian RM65 SPPV use in cattle was at a dose that is10 times stronger than that used in sheep. Turkey use Bakirköy SPPV at a dose three times that of sheep (Tuppurainen and Golan, 2016). Inactivated and live SPV vaccines have been shown to protect sheep at comparable levels (Boumart *et al.,* 2016). An independent efficacy study at the CODA-CERVA (with results yet to be published) on inactivated SPV and LSDV vaccines against LSDV is being carried out (Tuppurainen and Golan, 2016).

2.4 Risk factors of Lumpy Skin Disease

Several pathogen factors enable the disease to spread. The virus has high stability. Therefore, it can survive at ambient temperature for long periods, more so in dried scabs. Its high resistance to inactivation can enable it to survive in necrotic skin nodules, desiccated crusts, infected tissue culture fluid and in air-dried hides (OIE, 2013).

The LSDV is susceptible to high temperatures, sunlight and pH extremes. However, the virus can survive well at low temperatures (OIE, 2013; Tuppurainen and Oura, 2012).

On the other hand, environmental factors that favour the spread of the disease include the varied agroclimatic zones. In a study by Gari *et al.* (2010) in Ethiopia, it was found that the risk for occurrence of LSD is higher in agro-climates on midland and lowland compared to the agro-climates on the highland. The reason for this phenomenon may be due the presence of large biting fly populations in the midland and lowland agro-climates as they experience warm and humid climates favourable for their multiplication (Troyo *et al.*, 2008; Tuppurainen and Oura, 2012).

Grazing and watering of cattle in communal areas is associated with the occurrence of LSD (Gari *et al.*, 2010). The risk of virus exposure and mechanical transmission by *Stomoxys* spp. and mosquitoes (*Aedes aegypti*) is enhanced by contact and intermingling of different herds in post-harvest fields (Chihota *et al.*, 2001; Gari *et al.*, 2010; Waret-Szkuta *et al.*, 2011). Farms bordering game areas where there is interface between wildlife and cattle is also a risk factor (Gomo *et al.*, 2017) as it is thought that there are some wildlife hosts of LSDV (Tuppurainen *et al.*, 2018) such as the African Cape Buffalo (Maclachlan and Dubovi, 2016). The disease has been reported in water buffaloes, giraffes and impalas (Carter and Wise, 2006).

The host also has a role to play in the spread of the disease. Cattle of all breeds, age groups and sex are considered to be at risk of being infected, with severe and serious complications. Regarding breed susceptibility, LSD Occurrence is higher in *Bos taurus* than in *Bos indicus* (Zelalem *et al.*, 2015a) and the disease is also severe in *Bos taurus* compared to *Bos indicus* since *Bos taurus* has a thin skin compared to the thick-skinned

Bos indicus (Coetzer, 2004) and possible decreased susceptibility of *Bos indicus* to ectoparasites (Ibelli *et al.*, 2012). The less susceptibility of Bos indicus to LSD which was first recognised in 1929 may not be due to innate immunity as it takes several years to develop the innate immunity as seen in N'Dama breeds of West Africa that are trypanotolerant (Murray *et al.*, 1982). However, calves are less susceptible than adults according to Zelalem *et al.* (2015a) but often experience more severe disease than adults (CFSPH, 2008; OIE, 2010; Tuppurainen and Oura, 2012) due to weak cellular immunity in calves (Hunter and Wallace, 2001). Introducing new animals into a herd was found by Birhanu (2012) to be highly associated with LSD occurrence.

Animal movements is also considered to be a risk factor (Woods, 1988; Zelalem *et al.*, 2015b). This occurs when animals are moved from place to place for vaccination, trade activity and in search of water and pasture during the dry season (Zelalem *et al.*, 2015b). Infected cattle moving into areas free of disease also increase the risk of spread of LSD (Sevik and Dogan, 2016).

Gari *et al.* (2010) found the risk factors for LSD occurrence as communal grazing, introduction of new cattle and watering management. However, communal grazing and watering was found not to be a significant risk factor (Zelalem *et al.*, 2015a). Warm season is associated with occurrence of Lumpy Skin Disease due to high insect activity ($p = 0.000$, OR = 4.224. CI = 1.13-7.57) (Zelalem *et al.*, 2015a). Occurrence of LSD has been more experienced in the midland agro-climatic zones than highlands due to high frequency of introduction of new animals (Gari *et al.*, 2012) and warm humid climates that support large populations of biting flies (Troyo *et al.*, 2008; Gari *et al.*, 2012; Zelalem *et al.*, 2015a). The disease is more prevalent along water courses during the dry weather (Woods, 1988; Coetzer, 2004) and rapidly spread during heavy rains due to increased vector distribution (Woods, 1988).

Windborne dispersal of vectors is also thought to be a risk factor (Yeruham *et al.*, 1995; Klausner *et al.*, 2017). The original infection in one of the villages in Israel is thought to have been transmitted by stable flies (*Stomoxys calcitrans*) blown by the wind from origin of the disease at El Arish located in Northern Sinai, or at Ismailiya and the Nile delta located in Egypt. A cow in the neighbouring village also became infected, and is thought to have been spread by a veterinarian who was attending to the first LSD cases (Yeruham *et al.*, 1995). However, stronger winds significantly diminish chances of vectors passive transfer by wind (Saegerman *et al.*, 2018). The vectors can also be transferred through vehicles transporting hay and straw (Klausner *et al.*, 2017).

The arthropod vectors are also very active in warm, wet and land covered areas. These environmental factors pose a risk for LSDV spread (Ali *et al.*, 2012). The complete range of vectors for transmission of LSDV has not well known (EFSA AHAW Panel, 2015). It is thought that the type of vectors vary according to the geographical regions that is influenced by the environment, temperature, humidity and abundance of the vectors (EFSA AHAW Panel, 2015; Gubbins *et al.*, 2018). The blood feeding arthropod vectors also have a chewing feeding behaviour where the chewing–regurgitating feeding mechanism maybe responsible for transmission of viruses (Lovisolo *et al.*, 2003).

2.5 Economics of lumpy skin disease control and prevention

The government of United States classifies Capripox viruses as potential agents for agri-terrorism (Tuppurainen and Oura, 2012). Therefore, LSD is a priority disease that needs to be controlled in order to enhance livelihoods of the affected people (GALVmed, 2018).

Generally, the disease can cause indirect or direct production losses. The direct losses accrue from reduced yields and alterations in the normal herd structure due to mortalities. Indirect losses include cost of management and control of LSD, limited access to markets and limited use of modern technologies (Rushton, 2009). A more detailed approach to assessment of direct and indirect losses caused by LSD has been developed and used recently in the Balkan countries by Casal *et al.* (2018).

Although LSD has low morbidity and mortality rates, it's economic importance in Africa is due to prolonged loss of production in dairy and beef cattle, loss of weight in infected cattle, and loss of traction for farms using cattle as a source of draught power (Tuppurainen and Oura, 2012; Klement, 2018). Additionally, mastitis and severe orchitis, which may lead to infertility have been reported (Ocaido and Kakaire, 2008; Gari *et al.*, 2011; Tuppurainen and Oura, 2012). Other losses include reduced quality of hides, meat, culling losses and cost of treatment (for secondary bacterial infection) and prevention of the disease (Yacob *et al.*, 2008; Gari *et al.*, 2011). Great financial losses are experienced at the national level. This is due to high costs of control and eradication of the disease, limitation of global trade in livestock and livestock products (Tuppurainen and Oura, 2012).

Mortality loss due to LSD infection is characterised by two factors: incidence and case fatality rates (Klement, 2018). The incidence rate depends on the abundance of vectors present, immune status of the host and the types of preventive measures in use against LSD (Gari *et al.*, 2011). Incidence rate in an affected herd can be as high as 85% if no prevention actions are taken (Tuppurainen and Oura, 2012). Case fatality rate is very difficult to estimate accurately because of two reasons. First, in the developed countries, sick animals are mostly culled. Secondly, the exact cause of natural death is not usually provided in the developing countries (Klement, 2018). The case fatality rate reported in Albania was 5.8% (EFSA AHAW Panel, 2015), 54.8% in Turkey (Sevik and Dogan, 2017) and 9.3 and 21.9% for Zebu and cross-breeds respectively in Ethiopia due to different breed susceptibilities (Gari *et al.*, 2011). The mortality due to LSD is usually 1 – 3% in most outbreaks (Tuppurainen and Oura, 2012). Cattle mortalities due to LSD was estimated to cost USD 756 per animal in a dairy farm in Jos Plateau of Nigeria (Adedeji *et al.*, 2017).

Reduced milk production is one of the losses caused by LSD outbreaks in affected farms (Klement, 2018). In Turkey, it was reported that milk loss of about 159 litres per lactation occurred for an affected lactating cow that survived (Sevik and Dogan, 2017). In Ethiopia, the milk loss was estimated at between 1.5 - 3% (51 - 312 litres) per lactation for affected lactating cow in Zebu and cross-breed cattle, respectively (Gari *et al.*, 2011). However, both studies did not detail how milk loss was estimated (Klement, 2018). The reduction in milk production of 51.5% was also reported in farms in Jordan (Abutarbush *et al.*, 2015). Furthermore, a recent study in Ethiopia by Molla *et al.* (2017) showed 74% loss in milk production within 2.5 months of disease outbreak, while another study also estimated a milk production loss of 3.26% in Ethiopia (Hailu *et al.*, 2015).

Lumpy skin disease losses in beef cattle are related to the interference of the usual dynamics of the herd. These include reduced reproductive rates and weight gains in breeding and finished stocks, respectively (Klement, 2018). A 23.1% decrease in bodyweight has been reported in Jordan (Abutarbush *et al.*, 2015) and 1.2% beef loss in Ethiopia by Hailu *et al.* (2015). A study by Gari *et al.* (2011) in Ethiopia reported that the annual offtake rates in beef cattle reduced by 1.2% for zebu cattle and 6.2% for cross-breed cattle.

Lumpy skin disease has been found to cause abortions and infertility (Tuppurainen and Oura, 2012; Sevik and Dogan, 2017). However, it is still not clear how LSD directly causes the abortions and infertility (Klement, 2018). It could be as a result of virus replication in essential cells and direct destruction or indirect damages of organ function as a result of host immune system responding to the presence of viral proteins (Baron *et al.*, 1996). The disease also causes damage to the hides (Tuppurainen and Oura, 2012). Occurrence of the disease during the cropping season in areas where animal draught power is used for farming results in losses of farming days. In Ethiopia, oxen affected by LSD that survived led to a loss of an average of 16 days of draught power (Gari *et al.*, 2011), a median loss of 10 days (Molla *et al.*, 2017) and estimated draft power loss of 2.52% (Hailu *et al.*, 2015).

Economic impact of LSD is not only at the specific farms affected, but extends to impact the consumers, other members of the society especially the taxpayers, employment and income in affected communities and international trade (Thrusfield, 2005; Klement, 2018). Quarantine of the farms surrounding the infected farms restrict free movement of cattle to grazing areas and markets. Although the benefits of quarantine may be more than the costs, livestock owners in non-infected farms may have to bear some of these costs. Therefore, any disease control decision should identify and take into account these costs (Peck and Bruce, 2017).

Other control expenditures include vaccination, drugs, personnel and stamping out. These control costs are incurred either by the owners of infected cattle or the government through taxpayers' money (Klement, 2018). A cost estimate of these control expenditures generalizable between countries is difficult to come up with. This is because the different countries apply different combinations of control measures and the value of cattle differ from country to country (Klement, 2018). This is well demonstrated in the Europe epidemic of 2015 – 2016 (EFSA AHAW Panel, 2015; Agianniotaki *et al.*, 2017). The countries apply different control measures due to the differences in legislation that inform the control policies that is unique to each country (Peck and Bruce, 2017).

In Jordan, Abutarbush *et al.* (2015) estimated the cost of supportive treatment of cattle affected by LSD at £ 28 per animal. In Albania, the cost of supportive treatment was estimated at € 28.7 per animal (Karalliu *et al.*, 2017) and € 31.1 per animal (Casal *et al.*, 2018). In Bulgaria, the estimated cost of treatment was € 0.1 per animal, which is much lower because the animals were slaughtered shortly after positive confirmation of LSD infection (Casal *et al.*, 2018).

A general cost of LSD and control measures for all countries is difficult to estimate. First, the countries are affected differently by the disease. Secondly, there is a difference in production structures of animals and how the different countries implement the various control approaches as seen in the Balkan outbreak of 2016 – 2017 (Casal *et al.*, 2018; Klement, 2018). In this outbreak, a total of € 20.9 million was used in the control of disease in the three countries. The amount used was € 8.6 million, € 6.7 million and € 5.3 million in Bulgaria, Former Yugoslav Republic of Macedonia and Albania, respectively. The average cost per affected herd and per affected animal in affected herd was € 6,994 and € 147 for Bulgaria, € 3,071 and € 258 for Yugoslav Republic of Macedonia, € 869 and € 539 for Albania, respectively (Casal *et al.*, 2018). The government assumed 78% - 91% of the total cost in all the countries except in Albania where the government took responsibility for 39% of the total cost of the disease control (Casal *et al.*, 2018). Partial stamping out of clinically infected animals seemed to be the most effective method of LSD control as shown in the Former Yugoslav Republic of Macedonia where only four outbreaks were experienced in 2017. This method had also been proposed by EFSA (2016). Albania carried out vaccination with no culling of infected cattle and reported 372 new cases in 2017, majority being from non-vaccinated herds. Bulgaria on the other hand applied a stricter (and expensive) measure and experienced no outbreaks in 2017. The measures included complete stamping out of infected herds and compensation for all the cattle, a rapid vaccination campaign and aerial fumigation of vectors (Casal *et al.*, 2018). This aerial fumigation has come under criticism as it is expensive, environmental unfriendly and a concern to public health and food chain (Klement, 2018). Vaccinations decreased the number of cases dramatically in these three Balkan countries and reduced the cost of disease from € 12.6 million to € 0.5 million. Therefore, high coverage vaccinations with homologous vaccine is the most cost-effective measure for reducing LSD virus spread (Casal *et al.*, 2018). The vaccination efficacy in Bulgaria was 96% and 48% - 85% in Albania (EFSA, 2018). Use of effective vaccines such as the attenuated Neethling vaccine (Ben-Gera *et al.*, 2015) is economical so long as the vaccine does not cause post-vaccination LSD outbreak that may result to trade restriction.

Despite the low efficacy of some vaccines used against LSD, vaccination in Ethiopia has been shown to be an inexpensive way to reduce LSD induced losses (Gari *et al.*, 2011). Additionally, devoting resources to development of new generation combined vaccines such as for control of Rift Valley Fever and LSD is thought to yield high net returns upto an estimated USD 982,837 net present value as shown in simulations done in South Africa for dairy operations (Mdlulwa *et al.*, 2018). The net benefit of LSD control through annual vaccination was estimated at 4USD per head (Hailu *et al.*, 2015).

The losses due to international trade limitations vary significantly between countries (Klement, 2018). A study in Borena bull market in Ethiopia reported that the losses due to rejection of bulls affected by LSD was more than double the losses caused by mortality (Alemayehu *et al.*, 2013). The potential losses from trade suspensions in the European Union countries is estimated to be higher compared to mortality losses as they have stricter trade restrictions (Klement, 2018). For example, the decline in export of cattle in Bulgaria reduced from 10,000 heads of cattle in 2014 to 605 in 2016 (94% decrease) due to blue tongue outbreaks (Klement, 2018). Apart from the effects of trade restrictions on live animals, meat and dairy, trade in genetic resources can also be affected as Irons *et al.* (2005) reported that LSD virus can be secreted in semen. Countries in the trade of exporting bull semen will therefore incur high losses (Klement, 2018). The LSD control policies in different countries can therefore be influenced by international code of conduct governing trade. Despite numerous studies that have examined the economic implications of lumpy skin disease outbreaks around the World, to date there are no studies that have investigated the cost of LSD outbreaks in Kenya.

2.6 Case-control study design

This A case-control study design is useful in determining the association between the exposure and outcome of interest that could be disease or otherwise. In simple terms, the cases identified to have the outcome are assembled first and the controls recognized to be free of the outcome are assembled next. The exposures of the two groups are then retrospectively evaluated and the frequency of the exposures in the case and control groups are compared statistically (Lewallen and Courtright, 1998).

Case control studies are advantageous in that they are relatively fast, low-cost, and easy to carry out. The design is suitable for investigation of outbreaks and rare diseases or outcomes. The design produces rapid results and the deductions may be used to rationalize a more expensive and laborious longitudinal research (Lewallen and Courtright, 1998). However, case-control studies are subject to bias, cannot produce incidence data, challenging if record keeping is either insufficient or undependable and is prone to difficulty in the selection of controls (Lewallen and Courtright, 1998).

In the selection of cases, certain key elements must be put int consideration. These include sources of the cases, the definition of disease or the diagnostic criteria for the outcome and whether the incident or prevalent cases or both are to be included (Dohoo *et al.*, 2009). Cases are randomly sampled or selected based on specific inclusion criteria (Rose and Van der Laan, 2009) outlined above by Dohoo *et al.* (2009).

Controls chosen must be at comparable risk of developing the outcome. It should be representative of the population which experienced the exposure that gave rise to the cases. Usually, one control is selected for each case, but to improve the precision of association measures, more than one control (up to a maximum of four or five) per case can be selected

(Dohoo *et al.*, 2009). Matching is used, whereby the factors chosen to define how controls are to be comparable to the cases are established (Lewallen and Courtright, 1998). The main purpose for matching is to eliminate confounding, but it has also been shown to improve the efficiency of a study. Conditional logistic regression is used for analysis of such studies (Rose and Van der Laan, 2009) as the act of matching introduces potential bias. Matching can be done in two ways: individual matching and frequency matching. In individual matching, the researcher matches subject by subject while in frequency matching, the researcher ensures equal distribution of a variable among cases and controls (De Graaf *et al.*, 2011).

Several studies have used case-control study design in the field of veterinary science, although with issues compared to those in human health (Cullen *et al.*, 2016). Some of the recent ones used in cattle include septic arthritis (Chamorro *et al.*, 2019), Follicular Cystic Ovarian Disease (Sayad *et al.*, 2019), bovine tuberculosis (Milne *et al.*, 2019) and anthrax (Simbotwe *et al.*, 2019).

CHAPTER THREE: MATERIALS AND METHODS

3.1 Study Area

The study was carried out in Nakuru County, Kenya (Figure 3.1). The county has a human population of 1,603,325 people, projected to be 2,046,395 by 2017 (KNBS, 2009). The total number of households in the County was 409,836. The livestock population was estimated at 439,994 cattle, 505,035 sheep and 227,037 goats (KNBS, 2015). It is the fourth largest County in Kenya by human population. The County covers an area of 7,495 km^2 and comprises of nine administrative sub-Counties, 11 constituencies and 55 Wards (KNBS, 2015). The study population included all cattle herds present in the county. There are different cattle production systems in the county, with areas bordering Baringo and Narok counties practising pastoralism and areas around Nakuru town practising intensive cattle production.

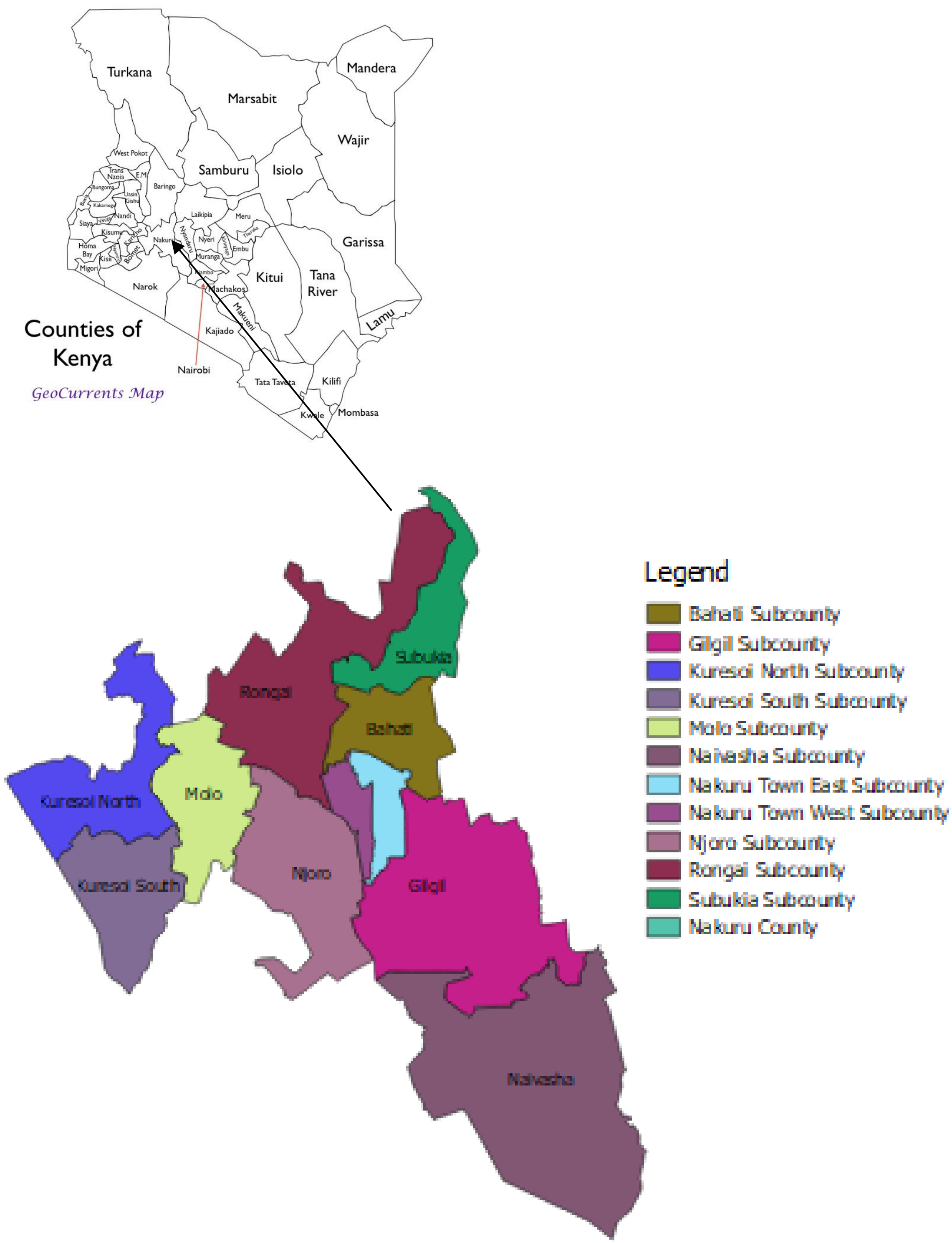

Figure 3.1 Map of Kenya showing the location of Nakuru County and the nine sub-counties.

3.2 Study design and sample size determination

This was a frequency matched case-control study and the sampling units were households that kept cattle. This is whereby matching is done subject by subject based on the potential confounder. This study design was adopted because the incidence of affected herds with LSD was thought to be low from local expert opinion. Potential case farms were identified by staff working for the Subcounty Veterinary Officer (SCVOs) in Nakuru County based on written records of attended cases. Subsequent case herds were identified through discussion with local animal health practitioners and farmers affected with disease. Unaffected households (controls) in the same village with the cases were all listed and assigned with a unique identification number and randomly selected until the desired number of control households was reached. The sample size was estimated using the epiR (version 0.9-99) package in R3.5.2 based on the methodology described by Dupont (1988). This uses the following equation to estimate sample size for frequency matched case control studies:

$$\mathbf{N} = \frac{\left(z_{\beta} v_{\varphi}^{1/2} + z_{\alpha/2} v_{1}^{1/2}\right)^{2}}{\left(e_{1} - e_{\varphi}\right)^{2}} \qquad [1]$$

Where,

Z = Number of standard deviations from the data point mean

v = Variance

e = Exponent

ψ = Odds ratio for exposure in case and controls.

α = Type I error probabilities

β = Type II error probabilities

N = Number of cases,

To optimise the efficiency of the study, four controls were matched for each case. Based on the assumption of 20% of controls having a risk factor of interest, in order to have 80% power to detect an odds ratio (OR) of 3.0 with 95% confidence, 41 cases and 164 controls were required. This assumed a moderate correlation in exposures between case and control exposures (rho = 0.2).

3.3 Case and control definitions

Case herds were defined based on clinical suspicion of LSD in at least one bovine demonstrating the characteristic clinical sign of raised, circular, firm, coalescing nodules with cores of necrotic material called sit-fasts which vary from 1 cm to 7 cm (CFSPH, 2008; CFSPH, 2011; Tuppurainen and Oura, 2012). Case farms were eligible for recruitment into the study if the suspected case occurred between September 2016 and October 2017.

Control herds were matched based on location being within the same village, and were eligible for recruitment into the study if no suspected LSD had been reported during the same time period or one year in the past.

3.4 Data Collection

Primary data were collected between October 2017 and February 2018 on household-level herd structures and putative risk factors for LSD. The questionnaire was administered to household heads, farm managers or any family members that was knowledgeable about the farm at least over the study period. Risk factors were chosen based on those described in the literature and included age category, breed, introduction of new animals, vaccination status against LSD, habits that encourage herd contact and mixing such as communal grazing land, forests and watering points, intermingling in post-harvest fields and communal dipping at the household level. These information were arranged into a questionnaire (Appendix 1) in a mixture of open ended and closed ended questions and administered using KoboCollect® mobile application. From case households, data were also collected on various aspects of direct and indirect losses due to LSD. Otherwise the questions asked were identical on case and control households.

The data collected on sources of direct losses from LSD outbreaks included number of cattle mortalities and loss in milk production, while the data on sources of indirect losses included cost of vaccination and treatment of sick cattle.

The cost of cattle mortalities was estimated by use of the number of cattle that died per sex and age category and their market prices. Prices of cattle were obtained from various livestock auction markets and farms breeding cattle for sale and were stratified by age and sex. Milk production loss was estimated by considering the reduction in milk loss per farm, the market price of milk and the duration of reduction of milk loss in lactating cattle affected by LSD.

The cost of vaccination was based on the amount of money households spent on animal vaccinations against LSD. Treatment costs was based on amounts of money spent by households on treatment of clinical cases of LSD in herds, prices of antibiotics they used in treatment of secondary wounds, consultation charges and transport charges that an animal health services provider would incur when they visited the farms. Feed and management costs were estimated at household level based on the amounts of money spent on purchase of feeds, and management costs associated with herding cattle. These included the cost of water, concentrates, forage, breeding, hired labour and family contribution to cattle rearing in terms of milking, spraying, herding, watering, feeding, cleaning of cattle sheds and treatment of cattle.

3.5 Data management and analysis

Data were downloaded from KoboCollect® mobile application and exported to MS Excel® 2010. They were then analysed using STATA 13® and R 3.3.3. The data analysis included estimating descriptive statistical measures including mean and standard deviation and inferential analysis and at all times the level of significance was set at 5%.

The strength of evidence for household-level univariable associations between putative risk factors and having at least one case of LSD was estimated using conditional logistic regression for binary or categorical variables and a unpaired t-test for continuous variables. Conditional logistic regression was performed including the matching variable (village) as a fixed effect in all models.

Variables that were associated on univariable conditional logistic regression analysis (at $P \leq 0.2$) were taken forward to the multiple conditional logistic regression analysis. The liberal P-value was chosen so as to include as many variables as possible in the multivariable analysis. The multivariable model was built using backward stepwise process. The maximum model (i.e. all variables significant on the univariable analysis) were included in the starting model arranged in order of the largest Wald statistic. The model was then fitted by performing likelihood ratio tests (LRT) to compare models with and without each of the variables. Variables were retained if the P-value of the LRT was ≤ 0.05. Interaction was tested in the final model using LRTs and the goodness of fit was tested using the Hosmer-Lemeshow test. Presence of collinearity was tested by use of variance inflation factors in STATA®.

The economic impact of the Lumpy Skin Disease outbreak was estimated by use of a framework described by Rushton *et al.* (1999) to estimate direct losses on production and indirect losses through the reaction and expenditure due to disease. According to this framework, livestock disease impacts on household incomes and national economy through direct and indirect losses. Direct losses are either visible (loss of milk production, loss of draught power, lower weight gains and dead animals) or invisible (fertility problems, changes in herd structure, delay in the sale of animals and animal products). On the other hand, indirect losses are either additional costs (costs related with disease prevention and control such as cost of vaccines, vaccine delivery, movement control, diagnostic tests and culled animals) or value of revenue foregone (use of sub-optimal breeds and denied access to markets both local and international). The framework is presented in the figure 3.2 below.

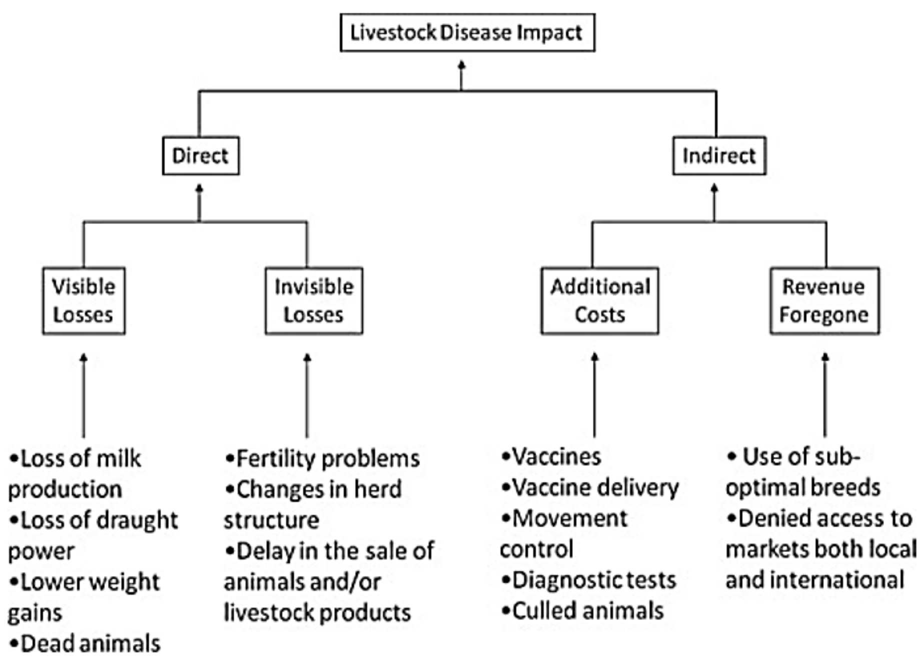

Figure 3.2: The Impact of Livestock Disease (Rushton *et al.*, 1999)

The approach used by Jemberu *et al.* (2014) in estimation of economic impact of Foot and Mouth Disease and by Molla *et al.* (2017) in estimation of economic impact of LSD in Ethiopia was adopted in the analysis of the estimated economic losses.

The economic cost of LSD vaccination was calculated as;

$$\mathrm{Vacost}_{ij} = \mathrm{NVa}_i * \mathrm{PVa}_i \qquad [2]$$

Where,

Vacost_{ij} = the vaccination cost for affected herd i with breed j (without consideration of subsidy if any);

NVa_i = the number of animals vaccinated;

PVa_i = the average per head expenditure on LSD vaccination (whether prior or post LSD);

The economic cost of LSD treatment was calculated as;

$$\mathrm{TrCost}_{ij} = \mathrm{NTr}_i * \mathrm{PTr}_i \qquad [3]$$

Where,

TrCost_{ij} = the treatment cost for affected herd i with breed j;

NTr_i = the number of animals treated;

PTr_i = the average per head expenditure to LSD treatment;

Economic losses due to milk loss per LSD affected herd were calculated as;

$$\mathrm{Lmilk}_{ij} = \mathrm{Ncow}_i * \mathrm{Q}_i * \mathrm{Tmilk}_i * \mathrm{Pmilk}_j \qquad [4]$$

Where,

Lmilk_{ij} = economic losses due to milk loss for herd i with breed j;

Ncow_i = number of lactating cows affected in herd i;

Q_i = average quantity of milk lost in liters per affected herd per day in herd i;

Tmilk_i = average duration of illness in days of affected lactating cows in herd i,

$Pmilk_j$ = average selling price of milk per litre reported by farmers in herd i. The economic loss due to mortality per herd was calculated as

$$Lmort_{ij} = (Nmortfcalf_i * Pfcalf) + (Nmortmcalf_i * Pmcalf) + (Nmortheif_i * Pheif) + (Nmortbull_i * Pbull) + (Nmortlact_i * Plact) + (Nmortdry_i * Pdry) \quad [5]$$

Where,

$Lmort_{ij}$ = economic losses due to mortality for a herd i with breed j;

$Nmortfcalf_i$ = number of female calves died in herd i;

Pfcalf = price of a female calf;

$Nmortmcalf_i$ = number of male calves died in herd i;

Pmcalf = price of a male calf;

$Nmortheif_i$ = number of heifers died in herd i;

Pheif = price of a heifer;

$Nmortbull_i$ = number of bulls died in herd i;

Pbull = price of a bull;

$Nmortlact_i$ = number of lactating cows died in herd i;

Plact = price of a lactating cow;

$Nmortdry_i$ = number of dry cows died in herd i;

Pdry = price of a dry cow;Total economic losses per herd were aggregated as the sum of all losses arising from milk loss, mortality, cost of treatment and cost of vaccination.

$$TEL_{ij} = Vacost_{ij} * TrCost_{ij} * Milk_{ij} * Mort_{ij} \quad [6]$$

Where,

TELij = total economic losses for herd i in a farm with breed j, The average of each of the economic losses per specific head of cattle present in the affected herds was obtained by dividing the specific economic losses in the herd by the total number of cattle in the herd. The average of each of the economic losses per affected herd was obtained by dividing the specific economic losses in the herd by the total number of herds affected.

CHAPTER FOUR: RESULTS

4.1 Characteristics of the households

A total of 41 case farms and 164 control farms were visited in six villages of Rongai sub-county. The other 8 sub-counties did not have any reported cases of LSD within the study period (reported LSD cases were from the year 2013 and earlier, which did not meet the case definition of this study). The majority (80.1%) of respondents were the farm owners in both case and control farms. The herd structure and sizes of the farms are shown in Table 4.1. There were more exotic breeds (71%) in the case herds than in the control farms (62%). However, the differences were not statistically significant at $p<0.05$ (Table 4.1). There were 448 cattle in the case farms and 1,183 in the control farms (Appendix 7).

4.2 Cattle management

Of the three herd sizes considered (Table 4.1), significantly ($p<0.05$) more case herds (37%) were large sizes than the control herds (22%). The distribution of grazing system was similar for both case and control herds. Zero grazing was the most popular grazing system being practised by 72% and 73% of the case and control farms, respectively. The artificial insemination (AI) appeared to be the widely method of breeding practised by 59% and 54% of the case and control farms, respectively (Table 4.1).

Table 4.1: Management practices on 41 case and 164 control farms in Nakuru County, 2017.

Variable	Level	Case farms (n=41)	Control farms (n=164)	Case farms (%)	Control farms (%)	P-Value
Herd size	Small (1 – 3)	11	61	26	37	0.03
	Medium (4 – 9)	15	67	37	41	
	Large (≥10)	15	36	37	22	
Grazing system	Tethering	1	9	2	5	0.94
	Zero-grazing	30	118	73	72	
	Free-range	10	37	24	23	
Watering system	In rivers	11	29	27	18	0.08
	Communal dams	4	38	10	23	
	Communal boreholes	0	1	0	1	
	Piped and harvested water	26	115	63	70	
Breeding	AI	24	89	59	54	0.83
	Own bull	0	8	0	4	
	Shared bull	17	66	41	41	
Vaccination against LSD	Yes	5	15	12	9	0.47
	No	36	149	88	91	
Replacement animals	Own herd	30	157	73	95.7	0.00
	From outside	11	7	27	4.3	

Key: AI=Artificial insemination, LSD=Lumpy Skin Disease

Vaccination against LSD in the farms appeared to be minimal. The vaccination was reported to have been carried out by 12% and 9% of the case and control herds, respectively, before the outbreak of LSD. Majority of the farmers only vaccinated their cattle against LSD, later after the outbreak of the disease, as a reaction to the LSD outbreaks. The source of replacement stock appeared to be mostly from own herds, although the practise was more in the control herds than in the case herds. The difference was significant ($p<0.05$) (Table 4.1).

Labour was sourced from outside the farms in 90.2% of the case farms and 30.5% of the control farms. The role of women in the farms was milking (83.3%) and for men and boys was spraying (50%) and herding (50%), respectively (Appendix 9).

4.3 Cattle productivity

The average milk production in Rongai sub-county was estimated at 10.4 litres per farm per day in both case and control farms. The production of exotic breeds of cattle was estimated at an average of 13.2 litres per farm per day and an average of 7.1 litres per farm per day for indigenous breeds.

The number of cattle slaughtered in abattoirs in Rongai Sub-county in the years 2016 and 2017 was 1,845 and 1,791 respectively. A kilogram of beef was sold at an average of Ksh. 400 per kilogram.

The prevailing market prices of different categories of cattle, some cattle products and inputs in Nakuru County as shown in Appendix 10.

4.4 Distribution of potential risk factors of LSD outbreaks in case and control herds

The distribution of the potential risk factors of LSD outbreaks in case and control herds is displayed in Table 4.3. There were significantly less indigenous breeds in the case herds (24.4%) than in the control herds (OR=0.07, $p=0.007$). Indeed, case herds were 14.3 times more likely to have exotic breeds of cattle relative to the control herd. Significantly ($P<0.05$) more large herds were in the case herds (37%) than in the control herds

(OR=3.51, p=0.029). Case herds were 3.5 times more likely to have large herds relative to the control herds.

Significant replacement of cattle from outside stocks were more in the case herds (27%) than in the control herds (4.3%) (OR=8.38, p=0.000). Indeed, case herds were 8.38 times more likely to have obtained replacement stocks from outside relative to the control herd.

4.4.1 Univariable analysis

The significant variables ($p \leq 0.05$) from the univariable logistic regression were replacement of cattle from outside stocks, indigenous breeds of cattle and large herd sizes (Table 4.2). Farms which replaced their herds with cattle from outside the farm were 8.4 times more likely to experience LSD outbreaks compared to farms that replaced from their own herds (OR=8.38, p=0.000). Herds with exotic breeds were 14.3 times more likely to experience LSD outbreaks relative to herds with indigenous (OR=0.07, p=0.007). Similarly, large herds were 3.5 times more likely to experience LSD outbreaks compared to the small herds (OR=3.51, p=0.029) (Table 4.2).

Table 4.2: Univariable analysis of the risk factors of Lumpy Skin Disease Outbreaks in Nakuru County.

Variable	Category	Cases (n)	%	Control (n)	%	OR	P-value	95% CI	
Breed	Exotic	29	70.7	102	62.2	Reference	-	-	-
	Indigenous	10	24.4	59	36.0	0.07	0.01	0.01	0.48
	Mixed	2	4.9	3	1.8	1.03	0.98	0.11	9.72
Herd size	Small (0 – 3)	11	26.8	61	37.2	Reference	-	-	-
	Medium (4 – 9)	15	36.6	67	40.9	1.76	0.25	0.67	4.64
	Large (≥10)	15	36.6	36	22.0	3.51	0.03	1.14	10.83
Dipping system	Home spraying	37	90.2	155	96.9	Reference	-	-	-
	Community dip	4	9.8	5	3.1	3.71	0.01	0.80	17.29
Breeding system	AI or own bull[a]	24	58.5	97	59.5	Reference	-	-	-
	Shared bull	17	41.5	66	40.5	1.11	0.84	0.402	.081
LSD Vaccination [b]	Yes	5	12.2	15	9.1	1.52	0.47	0.49	4.71
	No	36	87.8	149	90.9	Reference	-	-	-

Replaceme nt cattle	From own herd	30	73.2	157	95.7	Reference			
	From outside	11	26.8	7	4.3	8.38	<0.00	2.93	23.9
Watering system	In rivers	11	26.8	29	17.7	3.40	0.09	0.83	13.8
	Communal dams	4	9.8	38	23.2	1.25	0.74	0.34	4.55
	Communal boreholes	0	0.0	1	0.6	1.00	-	-	-
	Piped and harvested water	26	63.4	96	58.5	Reference	-	-	-
Grazing system	Tethering	1	2.4	9	5.5	0.38	0.38	0.05	3.24
	Zero-grazing	30	73.2	118	72.0	Reference	-	-	-
	Free-range	10	24.4	37	22.5	1.11	0.82	0.47	2.64
Season	Short rainy season (Aug – Nov)	15	36.6	62	37.8	Reference			
	Long rainy season (Apr – Jul)	13	31.7	51	31.1	1.06	0.90	0.42	2.7
	Dry season (Dec – Mar)	13	31.7	51	31.1	1.06	0.91	0.43	2.6

[a] AI and own bull was combined as only 4% (4/164) of the control farms used own bull.

[b] LSD vaccination between January 2016 and October 2017

4.4.2 Multivariable analysis

The variables from univariable analysis with $p \leq 0.2$ were included into the multivariable logistic regression model. The significant variables ($p \leq 0.05$) were "replacement of cattle from outside herds" (OR=7.28, p=0.001) and indigenous breeds of cattle (OR=0.07, p=0.015) (Table 4.3). The other variables that were significant in univariable analysis were not significant on multivariable analysis indicating that they were confounded by either unmeasured or measured variables. The Odds Ratios of the variables that remained significant in multivariable analysis did not change much (Tables 4.2 and 4.3) from univariable to multivariable analysis indicating that confounding was not a major problem.

4.4.3 Risk factors as thought by farmers

Most of the farmers (78.8%) did not have any idea on what could have caused the LSD outbreak. The top risk factors that the other farmers thought include mixing of affected with unaffected ones along the road (4.4%), spread by the wind (3.6%), spread by biting flies (3.6%), spread from the outbreak in that occurred in the area (2.2%), cattle from Loruk in Baringo county and Pokot being taken for sale in Marigat, Mogotio, Nakuru and Kenya Meat Commission within Nakuru county passing through the area (0.7%) and pastoralist cattle who may be brought into the area infected with LSD from Narok county in search of pasture in Nakuru county (0.7%).

Table 4.3: Multivariable analysis of the risk factors of Lumpy Skin Disease Outbreaks in Nakuru County (LRT p= 0.0045).

Variable	Category	Case (n)	%	Control (n)	%	OR	P-value	95% CI	
Replacement cattle	From own herd	30	73	157	96	Reference	-	-	
	From outside	11	27	7	43	8.70	<0.001	2.80	27.0
Breed	Exotic breeds	29	70.7	102	62.2	Reference	-	-	
	Indigenous	10	24.4	59	36.0	0.06	0.01	0.01	0.52
	Mixed breeds	2	4.9	3	1.8	0.47	0.56	0.04	5.8

4.5 Estimated economic impact of lumpy skin disease

Costs incurred on treatment of clinically infected cattle in case farms keeping indigenous cattle was estimated at an average of Ksh. 3,715; when compared with an average of Ksh. 5,003 for case farms keeping exotic breeds (p=0.6). On the other hand, cost of vaccination against LSD per case farm was estimated at an average of Ksh.888 for farms with indigenous breeds of cattle and an average of Ksh. 852 for farms with exotic breeds of cattle (p=0.9) (Table 4.4). Reduction in milk production during LSD outbreaks was estimated at an average of 2 litres per farm per day for farms keeping indigenous cattle and 10litres per farm per day for farms keeping exotic breeds of cattle. The duration of milk reduction was estimated in Ethiopia to be about 70 days post infection (Molla *et al.*, 2018). This would result to an average estimated loss of Ksh. 1,890 per farm for farms keeping indigenous cattle and Ksh. 11,275 per farmfor farms keeping exotic breeds (p=0.2). This is equivalent to an average estimated loss of Ksh. 831 per animal per farm keeping indigenous breeds of cattle and an average estimated loss of Ksh. 6,440 per animal per farm keeping exotic breeds of animal (p=0.3). The cost of mortalities during

LSD outbreaks was estimated at an average of Ksh. 621per farm keeping indigenous breed of cattle and an average of Ksh. 9,835 per farm keeping exotic breeds (p=0.2). The estimated average mortality loss at animal level is Ksh. 11 per animal per farm with indigenous breeds and Ksh. 2,142 per animal per farm keeping exotic breeds of cattle (p=0.2) (Figure 4.1). Based on these estimates, the total loss of LSD for farms keeping indigenous cattle was estimated at Ksh 7,114 and Ksh 26,965 for farms keeping exotic breed of cattle. Yet, if these farms implemented vaccination as a control strategy against LSD in farms, they would be able to save approximately, Ksh 6,226 and 26,113 for farms keeping indigenous and exotic cattle breeds, respectively. This level of resources can be reallocated to other LSD management functions within the cattle farms.

Table 4.4: Economic Impact Lumpy Skin Disease in Nakuru County, 2017.

Disease losses		**Animal category**	**Number of animal deaths per category (Total number of animals = 215)**	**Number of farms affected (Total number of farms =10)**	**Price of animal per category (KSH/animal)**	**Loss (KSH)**
Cattle deaths	Indigenous breeds of cattle	Lactating cows	2	1	15,066	30,132
		Dry cows	0	0	15,066	0
		Bulls	0	0	15,676	0
		Heifers	0	0	18,562	0
		Female calves	1	1	2,000	2,000
		Male calves	0	0	2,000	0
	Total		**3**	**2**		**32,132**
	Average loss for indigenous breeds per animal per farm					**621**
		Animal category	**Number of animal deaths per category**	**Number of farms affected (Total number of farms =31)**	**Price of animal per category (KSH/animal)**	**Loss (KSH)**

			(Total number of animals = 233)			
	Exotic breeds of cattle	Lactating cows	6	5	70,000	420,000
		Dry cows	2	2	50,000	100,000
		Heifers	8	4	70,000	560,000
		Bulls	1	1	30,000	30,000
		Female calves	2	1	5,000	10,000
		Male calves	4	1	3,500	14,000
	Total		23	14		1134000
	Average loss for exotic breeds per farm					9,835
	Breed category	**Milk price (KSH/Litre)**	**Milk reduction (litres per farm)**	**Duration of milk drop (Days)**	**Number of farms affected**	**Average loss per farm (KSH)**
Milk reduction per farm per outbreak	Indigenous breeds of cattle	36	1.5	70	2	1,890
	Exotic breeds of cattle	36	9.9	70	7	11,275
Cost of LSD control	**Item of cost and breed**	**Number of farms that effected the control**	**Number of animals**	**Loss per farm (KSH)**	**Average loss per animal per farm (KSH)**	**Average loss per farm (KSH)**
	Cost of treatment of LSD in indigenous case farms	8	37	28,270	2,194	3,715
	Cost of treatment of LSD in exotic case farms	29	33	42,300	2,684	5,003
	Cost of vaccination of LSD in indigenous case farms (Pre and post LSD)	7	130	5,795	39	888
	Cost of vaccination of LSD farms with exotic breeds (Pre and post LSD)	13	144	10,780	52	852

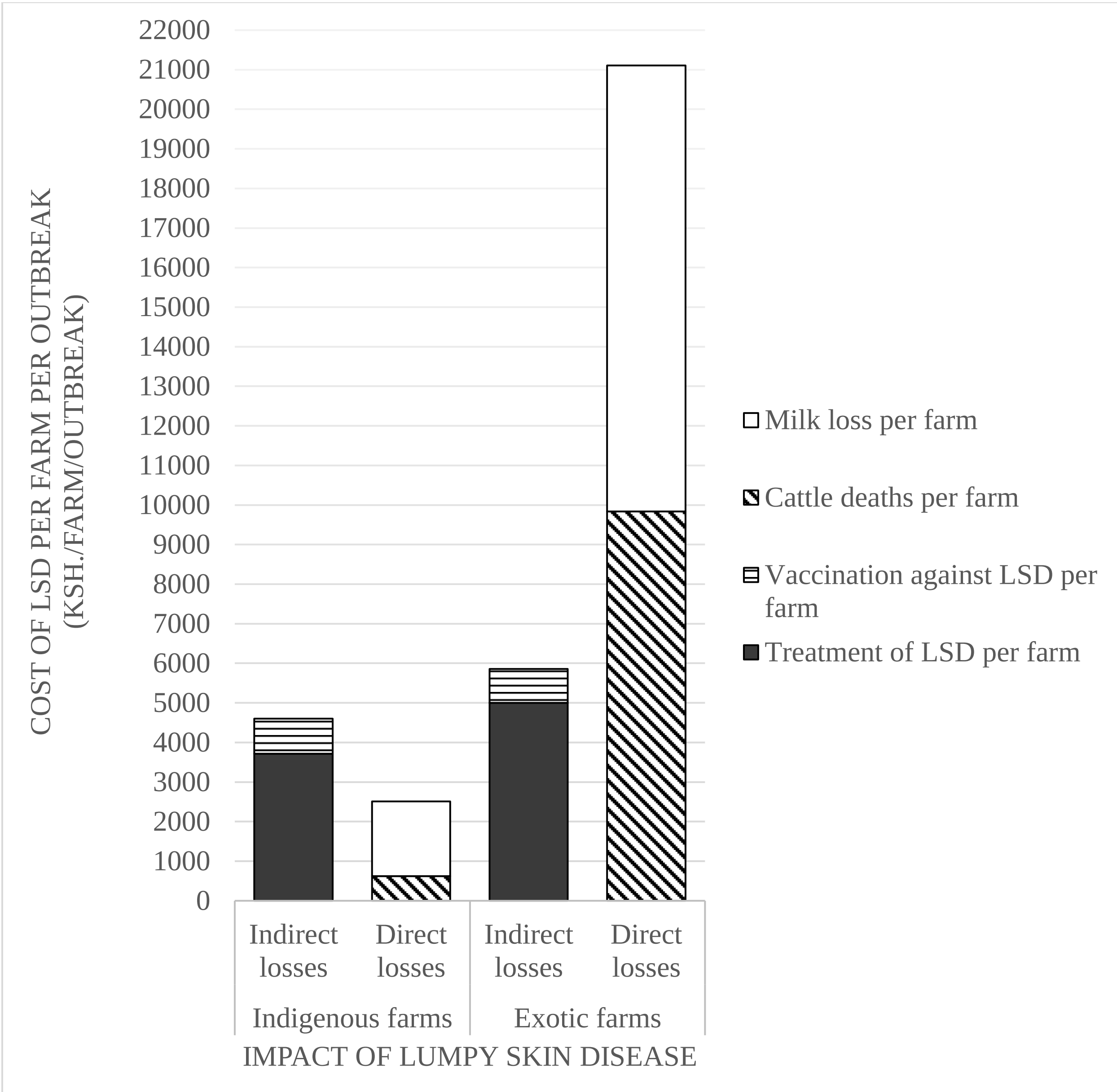

Figure 4.1 Economic impact of Lumpy Skin Disease outbreaks in case farms in Nakuru County, 2017.

NB: 1USD=101Ksh.

CHAPTER FIVE: DISCUSSION

The results of this study show that the average herd size for case and control farms was eight animals per farm. Farms keeping indigenous breeds of cattle had an average herd size of eleven while those keeping exotic breeds had an average herd size of seven. A study by Roderick *et al.* (1998) found out that herd sizes fluctuate seasonally due to changes in nutrition, herd mobility and disease mortality. This compares well with herd sizes of four (Murage and Ilatsia, 2011) and five (Muia *et al.*, 2011; Njarui *et al.*, 2012) estimated from previous studies conducted in Central Kenya (Nyandarua and Kiambu districts) and Eastern and Central Africa (Machakos and Wote in Kenya and Masaka in central Uganda) respectively. A recent study by Nyaguthii (2018) in Nakuru showed that the general average herd size was 5.5 and 8.2 in farms affected by Foot and Mouth Disease. The herd sizes can also vary according to the production system. In small scale dairy production system, herd sizes ranges from two to four cows, three to ten cows in small scale dairy and meat and over fifty five cows in large scale dairy and meat systems (Bebe *et al.*, 2003b; Murage and Ilatsia, 2011).

Majority of the study farms from this study kept exotic (Ayrshire and Friesian) breeds. Farms that kept indigenous breeds of cattle constituted about 34%. These results are consistent with results obtained in studies conducted in the Kenya highlands, where exotic breeds (Friesian and Ayrshire) constituted 62% of the study population and 22% were indigenous cattle (Bebe *et al.*, 2003a). Overall, Rege *et al.* (2001) estimated that indigenous breeds of cattle constituted 77% of cattle population and 23% exotic breeds and their crosses in Kenya. This shows that majority of cattle in Kenya are indigenous kept almost exclusively in pastoral production systems and the high milk yielding exotic breeds and their crosses kept in high potential areas where they are kept for milk production. Nakuru County is considered a high potential area, thus the composition of cattle breeds found.

In the current study, average of three animals were fed an average of two kilograms of concentrates per farm per day. Concentrate feeding is crucial in dairy enterprises for increased milk yield.

Milk yield in farms with indigenous breeds was seven litres per farm per day and double that in farms with exotic breeds. Farms reportedly spent a significant amount of money on water and forage in Nakuru County. Forage is an important feed source in the cattle systems where the cattle graze (James and Charles, 1996). Small scale dairy use one kilogram of concentrates to feed cows per day per milking per cow (Meme, 1998). Nyaguthii (2018) found out that the average milk production in Nakuru was 11 litres per farm per day. Muia *et al.* (2011) obtained similar estimates in a study carried out in Nyandarua, Kenya. In a study conducted by Njarui *et al.* (2012) in Machakos and Wote in Kenya and Masaka in Uganda, milk production also fluctuated with seasons ranging from three litres per cow per day in the dry season to nine litres per cow per day in the wet season. The findings of this study of thirty-six Kenya shillings per litre as the study was conducted in the last months of the wet season. Wet season is associated with abundance of feeds for the cattle and a resultant increased milk yield. There was also concomitant change in the price of milk with availability of milk – Ksh. 30 per litre in wet season and Ksh. 75 in dry season. Although this was not apparent in the current study, dairy farmers should be advised on the importance of conserving forage in the rainy season when it is plenty for use in times of scarcity such as the dry period and thus avoid production disruption.

The use of artificial insemination (AI) for breeding purposes was not common, practised by only 33% of the study farms. The cost of semen was cited as the inhibiting factor being an average of Ksh. 1,577 per dose. This was considered way out of reach for most small scale dairy farmers. As a result, farmers resorted to using either their own bulls or sometimes shared bulls between farms for breeding. This practise poses a high risk of introducing infectious diseases in their farms. In Central Kenya, the use of AI has been adopted by over 50% of surveyed farms (Murage and Ilatsia, 2011) and 40% in Nyandarua, Kenya (Muia *et al.*, 2011). Natural breeding using the bull has been found to be the preferred method in large scale dairy and meat production systems (Onono *et al.*, 2012). However, some researchers argue that progressive large dairy farms use AI and embryo technology extensively.

Hiring of farm labour was a common practise – 43% of the study farms had acquired farm labour from outside their farms, mostly from the neighbours. These results are consistent with those reported by Nyaguthii (2018) in farms surveyed in Nakuru County for foot-and-mouth disease outbreaks. Other activities in the farms were carried out by the members of the households.

The risk factors associated with occurrence of lumpy skin disease (LSD) from univariable analysis included breed, herd size and replacement stocks. However, in the final multivariable model, only breed and replacement stock retained their significance. Like for other infectious diseases, breed was strongly associated with LSD outbreaks presumably because indigenous breeds of cattle are less susceptible to ectoparasites that include blood feeding arthropods that transmit LSD compared to exotic breeds (Ibelli *et al.*, 2012). Replacement stocks obtained from outside the farm risks the introduction of infectious diseases into the farms. This is because culling of sick animals is commonly practiced by some farms. In one of the livestock auction markets, one farmer was selling his cow which had clinical signs of LSD with the only consequence of this being reduction in the price of the animal. These results agreed with those obtained in another study conducted in the three main Ethiopian agro-climatic zones (Gari *et al.*, 2010). Communal grazing and watering of cattle, practises that encourage mixing of cattle, were not significantly associated with LSD outbreaks, which is consistent with what was obtained by Zelalem *et al.* (2015a) in West Wolega zone of Ethiopia unlike in the study by Gari *et al.* (2010). These differences may have been due to other differences in the management of study herds and the study approach. It was rather surprising that there were no significant differences in the proportions of case and control herds that were vaccinated against LSD. One would have expected significantly more control herds than case herds to have been vaccinated. Information on the frequency of vaccinations and the durations since the last vaccinations were carried out was not sought in this study. The farmers could not remember the dates of vaccinations or the type of vaccines that were being administered to their cattle. So, the question remains for how long the LSD vaccine protected against LSD. Given the nature of the current study (case-control) with possibilities of confounders, this question cannot be answered easily.

The bulk of the loss of LSD was mainly associated with the indirect losses (vaccinations and treatment of secondary bacterial infections) in farms with indigenous breeds of cattle which was Ksh. 4,603. Farms with exotic breeds of cattle had the bulk of the economic losses in the direct losses at Ksh. 21,110. Farms with indigenous breeds of cattle incurred a total loss of Ksh. 7,114 while those keeping exotic breeds incurred a total loss of Ksh. 26,965. Much lower estimates were obtained in a similar study in Ethiopia at the equivalent of Ksh. 400 per cow. Similar to the current study, the costs were more in farms with exotic breeds of cattle relative to farms indigenous breeds of cattle. These differences may have occurred due to much higher doses of antibiotics administered to the much heavier exotic breeds for treatment of secondary bacterial infections. Additionally, farms keeping exotic breeds of cattle seek professional services of animal health practioners which is more costly compared to those keeping the indigenous breeds who buy the antibiotics over the counter and administer it to the cattle on their own. Secondary bacterial infection for LSD cases is the cause of most of the sickness and loss of production in herds (Woods, 1988). The losses are also high when the disease severity is high. The disease is more devastating in exotic breeds of cattle compared to indigenous breeds of cattle since exotic breeds have a thin skin compared to the thick-skinned indigenous breeds (Coetzer, 2004). Milk production due to LSD dropped from an average of 4 and 12 litres per farm per day to 3 and 2 litres per farm per day, a 25% and 83% drop for farms with indigenous and exotic breeds, respectively. In a study conducted in Ethiopia, milk reduction was by five litres per cow per day (Ayelet *et al.*, 2013). In other studies, milk production dropped by 50% and more (Woods, 1988). consistently It is evident from the current study that the major economic impact of LSD to the farmers lies in the indirect losses for farms keeping indigenous breeds of cattle (especially the cost of treatment) and direct losses in farms keeping exotic breeds (especially milk loss). Similar studies conducted in the North-Western and Central regions of Ethiopia have reported that the main factor of the economic loss at the herd level was due to mortality (one thousand dollars) followed by milk loss (one hundred and twenty dollars) (Molla *et al.*, 2017).

The low direct losses compared to indirect losses in farms keeping indigenous breeds of cattle from this study may be a cause of low incentive for the farmers to control LSD since the cost of prevention and control of LSD is more than the direct losses. Farms keeping indigenous breeds of cattle are majorly pastoralists. In a study on constraints of cattle production in pastoral areas, LSD was found to be a disease with low score for impact on livelihoods (5%) and low incidence (3%). It was ranked eighth among the thirteen prevalent diseases in pastoral areas (Onono *et al.*, 2013). The typical breed of cattle raised in the arid and semi-arid regions of Kenya and East Africa, where pastoralism is practised is indigenous breeds (Scarpa *et al.*, 2003).

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

- Majority of the farms in Rongai sub-county raised exotic breeds of cattle.
- Farm level factors that were positively associated with LSD outbreaks were herd size and source of replacement stocks while breed was negatively associated with LSD outbreaks.

  In the multivariable analysis, only two factors are retained their significance – breed and source of replacement stock.
- The indirect losses were estimated at Ksh. 4,603 and Ksh. 5,855 for farms keeping indigenous and exotic breeds of cattle respectively. This is in comparison to estimated direct losses of Ksh. 2,511 and Ksh. 21,110 for farms keeping indigenous and exotic breeds of cattle respectively.

6.2 Recommendations

- Farmers should be educated on the importance of maintaining closed herd, that is, to avoid acquiring replacement stock from outside their herds to avoid introduction of LSD in their farms.
- Controlled trials (field trials) should be carried out where two groups of herds, one vaccinated against LSD and the other one not vaccinated against LSD, are followed for a period of time and the incidence of LSD in the two groups compared. This will determine the status of the efficacy of LSD vaccines currently in use in Kenya.
- Farmers, especially those keeping exotic breeds of cattle should be trained on the best prevention and control strategies such as annual vaccination against the

disease, biosecurity measures such as introduction of animals examined and certified by the veterinary authorities to be free of infectious diseases.

- The county to adopt a policy whereby cattle from other counties accessing the area for trade, water and pasture be vaccinated against the disease prior to entry into the county. Vaccination against the disease can also be introduced at the points of entry of livestock into the county.
- The LSD has a potential to cause enormous economic impact. Farmers therefore need to employ the above control strategies in order to save the money that could have been incurred from the losses caused by the disease. These savings can be redirected into other profit-making enterprises in the farm.

REFERENCES

Abutarbush, S. M., Ababneh, M. M., Al Zoubi, I. G., Al Sheyab, O. M., Al Zoubi, M. G., Alekish M. O. and Al Gharabat R. J. (2015). Lumpy Skin Disease in Jordan: Disease Emergence, Clinical Signs, Complications and Preliminary-associated Economic Losses. *Transboundary and emerging diseases*, **62(5)**: 549 – 554 https://onlinelibrary.wiley.com/doi/full/10.1111/tbed.12177 Accessed on 22/03/2018

Adedeji, A.J., Adole, J.A., Dogonyaro, B.B., Kujul, N., Tekki, I.S., Asala, O.O., Chima, N.C., Dyek, Y.D., Maguda, A.S. and Aba-Adulugba, E.P., (2017). Recurrent outbreaks of lumpy skin disease and its economic impact on a dairy farm in Jos, Plateau State, Nigeria. *Nigerian Veterinary Journal*, **38(2)**:151-158.

African Union Inter-African Bureau for Animal Resources (2013). Lumpy Skin Disease http://www.au-ibar.org/lumpy-skin-disease *Accessed on 28/02/2018*

Agianniotaki, E.I., Tasioudi, K.E., Chaintoutis, S.C., Iliadou, P., Mangana-Vougiouka, O., Kirtzalidou, A., Alexandropoulos, T., Sachpatzidis, A., Plevraki, E., Dovas, C.I. and Chondrokouki, E. (2017). Lumpy skin disease outbreaks in Greece during 2015–16, implementation of emergency immunization and genetic differentiation between field isolates and vaccine virus strains. *Veterinary microbiology*, **201**: 78-84.

Ahmed, W.M. and K.S. Zaher (2008). Observations on lumpy skin disease in local Egyptian cows with emphasis on its impact on ovarian function. *African Journal of Microbiological Research*, **2**: 252-257.

Alemayehu, G., Zewde, G., and Admassu, B. (2013). Risk assessments of lumpy skin diseases in Borena bull market chain and its implication for livelihoods and international trade. *Tropical Animal Health and Production*, **45(5)**: 1153-1159.

Ali, H., Ali, A.A., Atta, M.S., Cepica, A., 2012. Common, emerging, vector-borne and infrequent abortogenic virus infections of cattle. *Transboundary and Emerging Diseases*, **59(1):** 11 - 25. https://doi.org/10.1111/j.1865-1682.2011.01240.x

Ayelet, G., Abate, Y., Sisay, T., Nigussie, H., Gelaye, E., Jemberie, S., and Asmare, K. (2013). Lumpy skin disease: Preliminary vaccine efficacy assessment and overview on outbreak impact in dairy cattle at Debre Zeit, central Ethiopia. *Antiviral Research*, **98(2):** 261–265. https://doi.org/10.1016/j.antiviral.2013.02.008

Ayres-Smith, R. A. (1960). The symptoms and clinical diagnosis of lumpy skin disease in Egypt *Veterinary Record*, **72**: 469-472.

Baldacchino F., Vithee M., Marc D., Florian D., Theeraphap C. and Ge´rard D. (2013). Transmission of pathogens by *Stomoxys* flies (*Diptera, Muscidae*): a review. *Parasite*, **20**: 26.

Baron, S., Fons, M., and Albrecht, T. (1996). Viral pathogenesis. In *Medical Microbiology. 4th edition*. University of Texas Medical Branch at Galveston.

Bebe, B. O., Udo, H. M. J., Rowlands, G. J., and Thorpe, W. (2003a). Smallholder dairy systems in the Kenya highlands: Breed preferences and breeding practices. *Livestock Production Science*, **82(2–3)**:117–127. https://doi.org/10.1016/S0301-6226(03)00029-0 *Accessed on 28/02/2018*

Bebe, B. O., Udo, H. M. J., Rowlands, G. J., and Thorpe, W. (2003b). Smallholder dairy systems in the Kenya highlands: Cattle population dynamics under increasing intensification. *Livestock Production Science*, **82(2–3)**:211–221. https://doi.org/10.1016/S0301-6226(03)00013-7 *Accessed on 28/02/2018*

Ben-Gera J., Klement E., Khinich E., Stram Y. and Shpigel N.Y. (2015). Comparison of the efficacy of Neethling lumpy skin disease virus and x10RM65 sheep-pox live attenuated vaccines for the prevention of lumpy skin disease. The results of a randomized controlled field study. *Vaccine*, **33(38)**: 4837 – 4842.

Birhanu (2012). *Assessments of the risk factors and financial impacts of LSD in selected districts of Tigray and Afar Regional States, Northeastern Ethiopia*. M.Sc. Thesis, Wollega University, Ethiopia.

Boshra, H., Truong, T., Nfon, C., Gerdts, V., Tikoo, S., Babiuk, L. A., and Babiuk, S. (2013). Capripoxvirus-vectored vaccines against livestock diseases in Africa. *Antiviral research*, **98(2):** 217-227.

Boumart Z., Daouam S., Belkourati I., Rafi L., Tuppurainen E., Tadlaoui K.O. and Harrak M. El (2016). Comparative innocuity and efficacy of live and inactivated sheeppox vaccines. *BMC Veterinary Research*, **12 (1)**: 133.

Bowden, T.R., S.L. Babiuk, G.R. Parkyn, J.S. Copps and D.B. Boyle (2008). Capripoxvirus tissue tropism and shedding: a quantitative study in experimentally infected sheep and goats. *Virology*, **371**: 380-393.

Burdin M.L., (1959). The use of histopathological examination of skin material for the diagnosis of Lumpy skin disease in Kenya. *Bulletin Des Epizooties En Afrique*, **7**: 27-36.

Carn V. M., and R. P. Kitching (1995). An investigation of possible routes of transmission of lumpy skin disease virus (Neethling). *Epidemiology and Infections*, **114**: 219–226.

Carter G.R. and D.J. Wise (2006). Poxviridae. *A Concise Review of Veterinary Virology*. Accessed from https://www.libyanvet.com/Books/10%20Poxviridae.pdf on 16/09/2019

Casal J, Allepuz A, Miteva A, Pite L, Tabakovsky B, Terzievski D, Alexandrov T and Beltran-Alcrudo D (2018). Economic cost of lumpy skin disease outbreaks in three Balkan countries: Albania, Bulgaria and the Former Yugoslav Republic of Macedonia (2016-2017). *Transboundary and Emerging Diseases*, **65(6):** 1680-1688 https://doi.org/10.1111/tbed.12926

Center for Food Security and Public Health (2008). Center for Food Security and Public Health, Iowa State University, College of Veterinary Medicine. *Accessed on 19/12/2016*

Center for Food Security and Public Health (2011). Center for Food Security and Public Health, Iowa State University, College of Veterinary Medicine. *Accessed on 19/12/2016*

Chamorro, M. F., Reppert, E. J., Robinson, L., Cernicchiaro, N., Biller, D., and Miesner, M. (2019). Factors associated with septic arthritis of the distal interphalangeal joint in beef cattle: A case-control study. *The Veterinary Journal*, **244:** 104-111.

Chihota, C.M., L.F. Rennie, R.P. Kitching and Mellor P.S. (2001). Mechanical transmission of lumpy skin disease virus by *Aedes aegypti* (*Diptera*: *Culicidae*). *Epidemiology and Infections*, **126**: 317-321.

Coakley, W. and Capstick, P. B. (1961). Protection of cattle against lumpy skin affecting small scale production of a tissue culture propagated virus vaccine. *Veterinary Science*, **2**: 369

Coetzer, J.A.W. (2004). Lumpy skin disease, in: Infectious diseases of livestock, edited by Coetzer, J.A.W. & Tustin, R.C. Cape Town: Oxford University Press Southern Africa, **2**:1268-1276.

Cullen, J.N., Sargeant, J.M., Makielski, K.M. and O'Connor, A.M., (2016). The case-control design in veterinary sciences: A survey. *Preventive Veterinary Medicine*, **134:** 179-187.

Davies F. G. (1982). Observations on the Epidemiology of Lumpy Skin Disease in Kenya. *The Journal of Hygiene*, **88 (1)**: 95-102 Accessed: 11-12-2018 on https://www.jstor.org/stable/3862979

Davies, F. G. (1991). Lumpy skin disease of cattle: A growing problem in Africa and the Near East. *World Animal Review*, **68(3)**: 37 – 42 Accessed on 11/12/18 on http://www.fao.org/docrep/u4900t/u4900t0d.htm

De Graaf, M. A., Jager, K. J., Zoccali, C., and Dekker, F. W. (2011). Matching, an appealing method to avoid confounding? *Nephron Clinical Practice*, **118(4):** c315-c318.

Dohoo, I.R., Martin, S.W. and Stryhn, H., (2009). Veterinary epidemiologic research. VER. *Inc., Charlottetown, PE, Canada*.

Dupont, W. D. (1988). Power calculations for matched case-control studies. *Biometrics*, **44**: 1157-1168.

EFSA Panel on Animal Health and Welfare (AHAW). (2015). Scientific Opinion on lumpy skin disease. *EFSA Journal*, **13(1):** 3986. https://doi.org/10.2903/j.efsa.2015.3986

European Food Safety Authority (2018). Lumpy Skin Disease: Vaccination is most effective control method. European Food Safety Authority (EFSA) *Accessed on 02/03/2018 from www.efsa.europa.eu*

European Food Safety Authority (2017). Lumpy skin disease. European Food Safety Authority. www.efsa.europa.eu/en/topics/topic/lumpy-skin-disease *Accessed on 29/06/2017*

European Food Safety Authority (2016). Urgent advice on lumpy skin disease. *EFSA Journal*, **4573**: 27. https://doi.org/10.2903/j.efsa.2016.4573

El-Tholoth M. and El-Kenawy A.A. (2016). G-Protein-Coupled Chemokine Receptor Gene in Lumpy Skin Disease Virus Isolates from Cattle and Water Buffalo (*Bubalus bubalis*) in Egypt. *Transboundary and Emerging Diseases*, **63(6)**: 288 – 295

Food and Agriculture Organization of the United Nations (1991). Lumpy skin disease of cattle: A growing problem in Africa and the Near East In: Animal genetic resources. *World Animal Review*, **68**:3

Food and Agriculture Organization of the United Nations (2015). Emergence of lumpy skin disease in Europe. *EMPRES WATCH*, **33.**

GALVMED (2018). Gates foundation and DFID award GALVmed $51 million to combat livestock disease. https://www.galvmed.org/news/gates-foundation-dfid-award-galvmed-51-million-to-combat-livestock-disease/ *Accessed on 27/09/2018*.

Gari G., Bonnet, P., Roger F. and Waret-Szkuta, A. (2011). Epidemiological Aspects and Financial Impact of Lumpy Skin Disease in Ethiopia. (NAHDIC) *Preventive Veterinary Medicine*, **102**: 274-283.

Gari G., Grosbois V., Waret-Szkuta A., Babiuk S., Jacquiet P. and Roger F. (2012). Lumpy skin disease in Ethiopia: seroprevalence study across different agro-climatic zones. *Acta Tropica*, **123(2):** 101 – 106.

Gari G., Waret-Szkuta A., Grosbois V., Jacquiet P. and Roger F. (2010). Risk factors associated with observed clinical lumpy skin disease in Ethiopia. *Epidemiology and Infections,* **138:** 1657-1666.

Gomo C., Kanonhuwa K., Godobo F., Tada O. and Makuza S. M. (2017). Temporal and spatial distribution of lumpy skin disease (LSD) outbreaks in Mashonaland West Province of Zimbabwe from 2000 to 2013. *Tropical animal health and production*, **49(3)**: 509-514.

Gubbins, S., Stegeman, A., Klement, E., Pite, L., Broglia, E., and Abrahantes, J. C. (2018). Inferences about the transmission of lumpy skin disease virus between herds from outbreaks in Albania in 2016. *Preventive Veterinary Medicine*, In press. https://doi.org/10.1016/j.prevetmed.2018.12.008.

Hailu, B., Gari, G., Tolosa, T., Beyene, B., and Teklue, T. (2015). Study on the epidemiological and financial impacts of clinical lumpy skin disease in selected districts of Tigray and Afar regional states, North Eastern Ethiopia. *International Journal of Current Research*, **7:** 17415-17425.

Ibelli, A.M.G., Ribeiro, A.R.B., Giglioti, R., Regitano, L.C.A., Alencar, M.M., Chagas, A.C.S., Paco, A.L., Oliveira, H.N.D., Duarte, J.M.S. and Oliveira, M.C.S., (2012). Resistance of cattle of various genetic groups to the tick *Rhipicephalus microplus* and the relationship with coat traits. *Veterinary Parasitology*, **186(3-4):** 425-430.

Hivisasa (2014). Naivasha vet department issues alert over lumpy skin disease outbreak https://hivisasa.com/posts/-------------naivasha-vet-department-issues-alert-over-lumpy-skin-disease-outbreak--------- *Accessed on 14/09/2019*

Hivisasa (2015). Vaccinate cattle against Lumpy Skin Disease, Lari farmers told https://hivisasa.com/posts/vaccinate-cattle-against-lumpy-skin-disease-lari-farmers-told *Accessed on 14/09/2019*

Hivisasa (2018). Ainabkoi farmers in agony as veterinary officer issues warning https://hivisasa.com/posts/935-farmers-cry-foul-over-lumpy-skin-disease *Accessed on 14/09/2019*

Hunter, P., and Wallace D. (2001). Lumpy Skin Disease in southern Africa: review of the disease and aspects of control. *Journal of the South African Veterinary Association*, **72(2).**

Innovative Diagnostics Vet (2017). Veterinary diagnostic tests. ID Screen® Capripox double antigen multi-species https://www.id-vet.com/produit/id-screen-capripox-double-antigen-multi-species/ Accessed on 18/12/2017.

Irons, P.C., Tuppurainen E.S.M. and Venter E.H. (2005). Excretion of lumpy skin disease virus in bull semen. *Theriogenology,* **63**: 1290-1297.

James, A. D., and Charles, A. B. (1996). Measuring the productivity of grazing and foraging livestock. *Agricultural Systems*, **52(2-3):** 271-291.

Jemberu, W.T., Mourits, M.C., Woldehanna, T. and Hogeveen, H., (2014). Economic impact of foot and mouth disease outbreaks on smallholder farmers in Ethiopia. *Preventive Veterinary Medicine*, **116(1-2)**: 26-36.

Karalliu, E., Boçi, R., Hatia, V., Prifti, V., Keçi, R., Manaj, B., and Koleci, X. (2017). A case study of lumpy skin disease outbreak in Rrapëz, Lushnje, Albania. *Albanian Journal of Agricultural Sciences*, special edition pp. 497-502.

Kitching R.P. (2003). Vaccines for lumpy skin disease, sheep pox and goat pox. Vaccines OIE List A. *Emerging Animal Diseases*, **114**: 161–167.

Kitching R.P. and Mellor P.S. (1986). Insect transmission of capripoxvirus. *Research in Veterinary Science,* **40**: 255–258.

Klausner, Z., Fattal, E., and Klement, E. (2017). Using synoptic systems' typical wind trajectories for the analysis of potential atmospheric long-distance dispersal of lumpy skin disease virus. *Transboundary and Emerging Diseases*, **64(2):** 398 - 410.

Klement, E. (2018). Economic Impact of Lumpy Skin Disease *In: Lumpy Skin Disease*. Springer, Cham. DOI: 10.1007/978-3-319-92411-3_3

Kenya National Bureau of Statistics (2009). Statistical abstract. The government printer, Nairobi.

Kenya National Bureau of Statistics (2015). Population and housing census 2009.

Knowledge Bylanes Kenya (2017). Quarantine issue in Mt Elgon following the outbreak of lumpy skin disease https://www.knowledgebylanes.co.ke/quarantine-issue-in-mt-elgon-following-the-outbreak-of-lumpy-skin-disease/ *Accessed on 14/09/2019*

Kruijshaar, M.E., Barendregt, J.J. and Hoeymans N. (2002). The use of models in the estimation of disease epidemiology *Bulletin of the World Health Organization,* **80(8)**: 622 – 628 http://www.who.int/bulletin/archives/80(8)622.pdf *Accessed on 21/03/2018*

Lewallen, S., and Courtright, P. (1998). Epidemiology in practice: case-control studies. *Community Eye Health,* **11(28):** 57 – 58.

Lovisolo, O., Hull, R., and Rösler, O. (2003). Coevolution of viruses with hosts and vectors and possible paleontology. *Advances in Virus Research,* **62:** 325-379.

Lubinga, J. C., Tuppurainen, E. S. M. Stoltsz, W. H. Ebersohn, K. Coetzer, J. A. W. and Venter E. H. (2013). Detection of lumpy skin disease virus in saliva of ticks fed on lumpy skin disease virus-infected cattle. *Experimental and Applied Acarology,* **61:** 129–138.

Lubinga, J. C., E. S. M. Tuppurainen, J. A. W. Coetzer, W. H. Stoltsz, and E. H. Venter, (2014). Evidence of lumpy skin disease virus over-wintering by transstadial persistence in *Amblyomma hebraeum* and transovarial persistence in *Rhipicephalus decoloratus* ticks. *Experimental and Applied Acarology*,**62:** 77–90.

Maclachlan N. and Edward J Dubovi J. E. (2016). Poxviridae, in: Fenner's Veterinary Virology 5th Edition edited by N. Maclachlan Edward J Dubovi Imprint: Academic

Press Accessed from https://www.sciencedirect.com/topics/neuroscience/lumpy-skin-disease on 16/09/2019

MacOwan, K.D.S. (1959). Observations on the epizootiology of lumpy skin disease during the first year of its occurrence in Kenya. *Bulletin of Epizootic Diseases of Africa,* **7**: 7-20.

Magori-Cohen, R., Y. Louzoun, Y. Herziger, E. Oron, A. Arazi, E. Tuppurainen, N.Y. Shpigel and E. Klement (2012). Mathematical modelling and evaluation of the different routes of transmission of lumpy skin disease virus. *Veterinary Research*, **43**:1

Mdlulwa, Z., Masemola, M., Chaminuka, P., and Madyo, S. (2018). Economic analysis of new generation vaccines for control of lumpy skin disease and Rift Valley Fever in South Africa. *Agrekon*, **1**: 1-16.

Mellor P.S., Kitching R.P. and Wilkinson P.J. (1987). Mechanical transmission of capripox virus and African swine fever virus by Stomoxys calcitrans. *Research in Veterinary Science,* **43**: 109 – 112.

Meme, M. F. (1998). Descriptive and Gross Margin analysis for the case study farmers. *PhD thesis, University of Reading, UK.*

Milne, G., Graham, J., Allen, A.R., Lahuerta-Marin, A., McCormick, C.M., Presho, E., Skuce, R.A. and Byrne, A., (2019). Characteristics of Northern Irish cattle herds without bovine tuberculosis infection. *Veterinary Record*, vetrec-2018.

Molla, W., de Jong, M. C. M., Gari, G., and Frankena, K. (2017). Economic impact of lumpy skin disease and cost effectiveness of vaccination for the control of outbreaks in Ethiopia. *Preventive Veterinary Medicine*, **147**: 100–107.

https://doi.org/10.1016/j.prevetmed.2017.09.003

Muia, J. M. K. ., Kariuki, J. N. ., Mbugua, P. N. ., Gachuiri, C. K. ., Lukibisi, L. B. ., Ayako, W. O. ., and Ngunjiri, W. V. (2011). Smallholder dairy production in high altitude Nyandarua milk-shed in Kenya: Status, challenges and opportunities. *Livestock Research for Rural Development*, **23(5)** *Article #108***.** Retrieved September 13, 2019, from http://www.lrrd.org/lrrd23/5/muia23108.htm

Murage, A. W., and Ilatsia, E. D. (2011). Factors that determine use of breeding services by smallholder dairy farmers in Central Kenya. *Tropical Animal Health and Production*, ***43*(1)**:199–207. https://doi.org/10.1007/s11250-010-9674-3

Murray, M., W.I. Morrison, and Whitelaw D.D. (1982). Host susceptibility to African trypanosomiasis: Trypanotolerance. *Advances in Parasitology*, **21**:1–68.

Nelson K. E., and Williams C. M. (Eds.) (2013). *Infectious disease epidemiology*. Jones and Bartlett Publishers, Boston, Massachusetts. https://books.google.co.ke/books?hl=en&lr=andid=SnYGIlHpix0C&oi=fnd&pg=PR1&dq=nelson+&+williams+2013&ots=r4bUPrPX_p&sig=Q6RRzr47lLA1waI6Iagoc8uKK-c&redir_esc=y#v=onepage&q=nelson%20&%20williams%202013&f=false *Accessed on 15/06/2018*

Njarui D M G, Kabirizi J M, Itabari J K, Gatheru M, Nakiganda A and Mugerwa S (2012). Production characteristics and gender roles in dairy farming in peri-urban areas of Eastern and Central Africa. *Livestock Research for Rural Development,* **24(122)**. Retrieved February 28, 2018, from http://www.lrrd.org/lrrd24/7/njar24122.htm

Nyaguthii D.M (2018). Occurrence and Risk Factors Associated with Foot and Mouth Disease in Smallholder Dairy Farms of Nakuru County, Kenya. *MSc. thesis, University of Nairobi, Kenya.* Accessed on 17/03/2019 on http://erepository.uonbi.ac.ke/handle/11295/105392

Ocaido M., Otim C.P. and D. Kakaire (2008). Impact of major diseases and vectors in smallholder cattle production systems in different agro-ecological zones and farming systems in Uganda. FVM, Makerere University, Kampala, Uganda. *Livestock Research for Rural Development,* **21(9).**

Omoga, D.C.A (2018). *Molecular based detection, validation of LAMP assay and Phylogenetic analysis of Capripoxvirus in Kenya* (PhD thesis, Jomo Kenyatta University of Agriculture and Technology, Kenya).

Office International des Epizooties (2010). Terrestrial Manual of Lumpy Skin Disease, Chapter 2.4.14. Version adopted by the World Assembly of Delegates of the OIE in May 2010, OIE, Paris. *Accessed on 18/12/2016*

Office International des Epizooties (2011). Lumpy Skin Disease. Terrestrial Animal Health Code. OIE, Paris. *Accessed on 18/12/2016*

Office International des Epizooties (2013). Lumpy Skin Disease. Aetiology, epidemiology, diagnosis, prevention and control references. OIE Technical Disease Cards. *Accessed on 18/12/2016*

Office International des Epizooties (2017). Lumpy skin disease. Chapter 2.4.13 *Accessed on 27/06/2017*

Onono, J. O., Wieland, B., and Rushton, J. (2012). Productivity in different cattle production systems in Kenya. *Tropical Animal Health and Production*, **45(1)**: 423–430. https://doi.org/10.1007/s11250-012-0233-y

Onono, J. O., Wieland, B., and Rushton, J. (2013). Constraints to cattle production in a semiarid pastoral system in Kenya. *Tropical animal health and production*, **45(6)** :1415-1422.

Peck, D., and Bruce, M. (2017). The economic efficiency and equity of government policies on brucellosis: comparative insights from Albania and the United States of America. *Revue scientifique et technique (International Office of Epizootics)*, **36(1)**: 291-302.

Rege, J. E. O., Kahi A.K., Okomo-Adhiambo M., Mwacharo J. and Hanotte O. (2001). *Zebu cattle of Kenya: Uses, performance, farmer preferences, measures of genetic diversity and options for improved use.* Animal Genetic Resources Research 1. ILRI (International Livestock Research Institute), Nairobi, Kenya. 103pp.

Roderick, S., Stevenson, P., and Ndungu, J. (1998). The production parameters influencing the composition and structure of pastoral cattle herds in a semi-arid area of Kenya. *Animal Science*, **66(3)**: 585–594. https://doi.org/10.1017/S1357729800009164

Rose, S., and Van der Laan, M. J. (2009). Why match? Investigating matched case-control study designs with causal effect estimation. *The International Journal of Biostatistics*, **5(1)**.

Rushton J. (2009). The economics of animal health and production. CAB International, London, UK.

Rushton J., Thorton, P.K. and Otte, M.J. (1999). Methods of economic impact assessment. *Revolutions in Science Technology*, **18(2)**:315 – 342. https://onlinelibrary.wiley.com/doi/full/10.1111/tbed.12565 *Accessed on 22/03/2018*

Saegerman, C., Bertagnoli, S., Meyer, G., Ganière, J.P., Caufour, P., De Clercq, K., Jacquiet, P., Fournie, G., Hautefeuille, C., Etore, F. and Casal, J. (2018). Risk of introduction of lumpy skin disease in France by the import of vectors in animal trucks. *PloS one*, **13(6)**: e0198506. https://doi.org/10.1371/journal.pone.0198506

Salib, F. A., and Osman, A. H. (2011). Incidence of lumpy skin disease among Egyptian cattle in Giza Governorate, Egypt. *Veterinary world*, **4(4)**.

Sayad, A., Koohi, M.K., Vodjgani, M., Abdi, K., Gharagozloo, F., Rezvanfar, M.A., Akbarein, H., Baeeri, M. and Abdollahi, M., (2019). An Evaluation of the Plasma Levels of Frequently Used Pesticides in Dairy Cattle and Its Possible Correlation with the Occurrence of Follicular Cystic Ovarian Disease: A Case-Control Study. *Novelty in Biomedicine*, ***7*(2):** 55-63.

Scarpa, R., Ruto, E. S., Kristjanson, P., Radeny, M., Drucker, A. G., and Rege, J. E. (2003). Valuing indigenous cattle breeds in Kenya: an empirical comparison of stated and revealed preference value estimates. *Ecological Economics*, **45(3)**: 409-426.

Şevik, M., and Doğan, M. (2017). Epidemiological and molecular studies on lumpy skin disease outbreaks in Turkey during 2014–2015. *Transboundary and emerging diseases*, **64(4)**:1268-1279.

Sharawi S.S. and Abd El-Rahim I.H. (2011). The utility of polymerase chain reaction for diagnosis of lumpy skin disease in cattle and water buffaloes in Egypt. *Revolutions in Science Technology,* **30**:821–30.

Simbotwe, M., Mulenga, E., Furuta, Y., Munkombwe Muuka, G., Hang'ombe, B.M. and Higashi, H., (2019). Geographic distribution of cattle anthrax in Western Zambia. *Japanese Journal of Veterinary Research*, **67(2):** 195-202.

Somasundaram, M. K. (2011). An outbreak of lumpy skin disease in a Holstein Dairy Herd in Oman: a clinical report. *Asian Journal of Animal Veterinary Advancements,* **6:** 851–859.

Sprygin, A., Pestova, Y., Wallace, D. B., Tuppurainen, E., and Kononov, A. V. (2019). Transmission of lumpy skin disease virus: a short review. *Virus research*, **269**.

Standard Group PLC (2015). Quarantine in six sub-counties over epidemic https://www.standardmedia.co.ke/article/2000147238/quarantine-in-six-sub-counties-over-epidemic *Accessed on 14/09/2019*

Standard Group PLC (2018a). Farmers accuse county of failing to vaccinate livestock https://www.standardmedia.co.ke/article/2001295092/farmers-accuse-county-of-failing-to-vaccinate-livestock *Accessed on 14/09/2019*

Standard Group PLC (2018b). Farmers risk losing livestock as outbreak of lumpy skin disease bites https://www.standardmedia.co.ke/health/article/2001298744/fear-as-lumpy-skin-disease-spreads-in-murang-a *Accessed on 14/09/2019*

Standard Group PLC (2019). Disease outbreak leaves trail of livestock deaths https://www.farmers.co.ke/article/2001294702/residents-of-baringo-south-counting-losses-after-an-outbreak-of-lumpy-skin *Accessed on 14/09/2019*

Tageldin, M. H., D. B. Wallace, G. H. Gerdes, J. F. Putterill, R. R. Greyling, M. N. Phosiwa, R. M. Al Busaidy, and Al Ismaaily S. I. (2014). Lumpy skin disease of cattle: an emerging problem in the Sultanate of Oman. *Tropical Animal Health and Production,* **46**: 241–246.

Thrusfield M (2005). The economics of infectious diseases. *In: Veterinary epidemiology*. Blackwell Science, London: 357–367

Tuppurainen, E.S.M., Babiuk, S., and Klement, E. (2018). Lumpy Skin Disease. VI, 109. Springer Int Publishing. DOI: 10.1007/978-3-319-92411-3

Troyo, A., O. Calderon-Arguedas, D.O. Fuller, M.E. Solano, A. Avendano, K.L. Arheart, D.D. Chadee and Beier J.C. (2008). Seasonal profiles of *Aedes aegypti* (*Diptera: Culicidae*) Larval habitats in an urban area of Costa Rica with the history of mosquito control. *Journal of Vector Ecology*, **33**: 1-13.

Tuppurainen E. and Galon N. (2016). Lumpy skin disease: Current situation in Europe and neighbouring regions and necessary control measures to halt the spread in South-East Europe**.** Europe – OIE Regional Commission.

Tuppurainen E. S. M., E. H. Venter, J. L. Shisler, G. Gari, G. A. Mekonnen, N. Juleff, N. A. Lyons, K. De Clercq, C. Upton, T. R. Bowden, S. Babiuk and L. A. Babiuk (2015). Review: Capripoxvirus Diseases: Current Status and Opportunities for Control. *Transboundary and Emerging Diseases,* **64(3)**: 729 – 745.

Tuppurainen S. M., J. A. W. Coetzer, W. H. Stoltsz, and E. H. Venter (2014a). Evidence of lumpy skin disease virus over-wintering by transstadial persistence in *Amblyomma hebraeum* and transovarial persistence in *Rhipicephalus decoloratus* ticks. *Experimental and Applied Acarology,* **62**: 77–90.

Tuppurainen, E.S., Pearson, C.R., Bachanek-Bankowska, K., Knowles, N.J., Amareen, S., Frost, L., Henstock, M.R., Lamien, C.E., Diallo, A. and Mertens, P.P. (2014b). Characterization of sheep pox virus vaccine for cattle against lumpy skin disease virus. *Antiviral Research*, **109(1):** 1–6. https://doi.org/10.1016/j.antiviral.2014.06.009

Tuppurainen, E. S. M., J. C. Lubinga, W. H. Stoltsz, M. Troskie, S. T. Carpenter, J. A. W. Coetzer, E. H. Venter and Oura C. A. L. (2013a). Mechanical transmission of lumpy skin disease virus by *Rhipicephalus appendiculatus* male ticks. *Epidemiology and Infections*, **141:** 425–430.

Tuppurainen, E. S. M., J. C. Lubinga, W. H. Stoltsz, M. Troskie, S. T. Carpenter, J. A. W. Coetzer, E. H. Venter and Oura C. A. L., (2013b). Evidence of vertical transmission of lumpy skin disease virus in *Rhipicephalus decoloratus* ticks. *Tick Borne Diseases*, **4**: 329–333.

Tuppurainen, S.M. (2005). The detection of lumpy skin disease virus in samples of experimentally infected cattle using different diagnostic techniques, *Onderstepoort*. *Journal of Veterinary Research*, **72(2)**: 153-64.

Tuppurainen, E.S.M. and Oura C.A.L. (2012). Review: Lumpy Skin Disease: An Emerging Threat to Europe, the Middle East and Asia. *Transboundary and Emerging Diseases*, **59(1)**: 40 - 48.

Wallace, D. B., and Viljoen, G. J. (2005). Immune responses to recombinants of the South African vaccine strain of lumpy skin disease virus generated by using thymidine kinase gene insertion. *Vaccine*, **23(23)**: 3061-3067.

Waret-Szkuta A., A. Ortiz-Pelaez, F. Roger, D.U. Pfeiffer and Guitian F.J. (2011). Herd contact structure based on shared use of water points and grazing points in the Highlands of Ethiopia. *Epidemiology and Infections,* **139(6)**: 875 – 885.

Weiss, K.E. (1968). Lumpy skin disease virus. *Virology monographs,* **3**:111 – 131.

Woods, J. A. (1988). Lumpy skin disease—a review. *Tropical Animal Health and Production*, **20(1)**: 11-17.

Yacob, H., B. Nesanet and Dinka A. (2008). Part II: Prevalence of major skin diseases in cattle, sheep and goats at Adama Veterinary Clinic, Oromia regional state, Ethiopia. *Revue de Médecine Veterinaire,* **159 (8-9)**: 455 - 461.

Yeruham, I., Nir, O., Braverman, Y., Davidson, M., Grinstein, H., Haymovitch, M., and Zamir, O. (1995). Spread of lumpy skin disease in Israeli dairy herds. *Veterinary Record*, **137:** 91 - 91.

Zelalem Abera, Hailu Degefu, Getachew Gari and Menbere Kidane (2015a). Sero-prevalence of lumpy skin disease in selected districts of West Wollega zone, Ethiopia. *BMC Veterinary Research,* **11**:135

Zelalem Abera, Hailu, D., Getachew, G. and Zelalem Ayana (2015b). Review on Epidemiology and Economic Importance of Lumpy Skin Disease. *International Journal of Basic and Applied Virology,* **4(1):** 8 – 21

APPENDICES

Appendix 1: Questionnaire on risk factors for LSD and the economic impact of the disease

Section A: INTRODUCTION

Date: ________________Subcounty: _________________Sub-Location: _______________

Village: _______________ Exact location (GPS coordinates): ________________________

Section B: FARM INFORMATION

1. What is the relationship of the respondent to the farm?

   1= Owner 2 = Manager 3= Other (Specify) _________________

2. How do you control ticks?

   1= Home spraying 2 = Communal cattle dip 3= Other (Specify) ________________

3. What is the frequency of acaricide dipping/spraying?

   1= Twice a week 2 = Once a week 3= Biweekly 4= Other (Specify) _______________

4. How many cattle in total (plus calves) do you currently own? _________________

5. What breeds and number of cattle do you own in each of the following categories?

Breed	No. Lactating	No. female calves	No. Male calves	No. heifers	No. bulls	No. dry cows

6. Has there been an outbreak of LSD in this farm? (You may refer to the pictures for clinical presentation of LSD) ________________

   1= Yes; 2=No

7. If yes, when did the LSD outbreak occur? ________________

8. What clinical signs of the Lumpy Skin Disease were seen/observed?

   ____

   ____

   ____

   ____

9. How many cattle contracted the disease during the outbreak? ______________

10. What was the total number of cattle that died due to the disease outbreak? _________

11. What was the total number of cattle that recovered from the disease? ____________

12. What was the total number of unaffected cattle? ________________

13. For the cattle that died, what breed(s) and number were affected according to the following categories?

Breed	No. Lactating	No. female calves	No. Male calves	No. heifers	No. bulls	No. dry cows

14. For the cattle that died of LSD and were lactating, how much milk in litres were you getting from them before they died of LSD? _________________

15. For the cattle that recovered from LSD and were lactating, how much milk in litres per day were you getting from them before they were affected by LSD? ____________

16. How much milk in litres per day were you getting from the cows after they were affected by LSD? _____________

17. How much milk in litres per day were you getting from the cows before the LSD outbreak in the farm? _________________

18. Has there been any introduction of new cattle into the herd since Sept last year? ___

    1=Yes; 2= No

19. If yes, when was it? (mm/yy) _________________

20. What was the purpose of the introduction? Select as many as applicable

    1=Replacement animal; 2=Increasing the herd 3=Bull service

    4= Other (Please specify) ___________________

21. How many animals were introduced to the farm?

22. Where did the cattle come from? _________________

23. Have you ever carried out vaccination against LSD since 2016? _________________

    1=Yes; 2=No

24. If yes, when was it carried out? _________________

25. How many animals were vaccinated? _______________

26. What was the cost of vaccination (Ksh/animal)? _________________

27. Did any of the vaccinated cattle contract LSD? _________________

    1= Yes; 2=No

28. If no vaccination was carried out, what was the reason for not vaccinating?

____

29. Where do you always graze your cattle (Tick as many as possible)?

1. Grazing along the feeder roads

2. Grazing along the main roads

3. Grazing in shared post-harvest fields

4. Grazing in private land

5. Grazing in shared land

6. Zero-grazing

7. Tethering

8. Forest

9. Game reserve/park/conservancy

10. Other (Please specify) ____________________________________

30. Where do you always water your cattle (Tick as many as possible)?

1. Shared river

2. Shared dam/pond

3. Private access to river

4. Private dam/pond

5. Own borehole

6. Piped water

7. Harvested rain water

8. Other (Please specify) ______________________________________

31. What factor(s) do you think may have contributed or contributes to the disease outbreak in this area? ____

32. How many cattle that contracted LSD were treated (for secondary bacterial infection and wounds etc)? __________________

33. How much did you spend on the treatment of LSD per animal? __________________

34. If water for cattle is bought, how much do you spend per month__________________

35. How many animals do you feed with the concentrate feed per day? __________________

36. How much in kg do you feed each animal per day__________________

37. What is source of the forage/hay__________________

38. How often do you buy forage __________________?

39. What amount of forage/hay do you buy__________________?

40. Which means of breeding do you use? *1. Artificial insemination* *2. Bull*

41. How much did you pay for the last breeding? __________________

42. How much do you spend on hired labour per month__________________?

43. What roles do the following family members play on cattle production? (Tick as many as appropriate)

	Father	Mother	Son(s)	Daughter(s)
Spraying of cattle				
Cattle herding				
Fetching grass for the cattle				
Cleaning the cattle shed				
Fetching cattle water				
Taking cattle to the water place				
Cattle treatment				

Appendix 2: Unpaired T-test of continuous variables for case and control farm groups in Nakuru County

Variable	Group	No. of Observations	Mean	Standard Error	Standard Deviation	[95% Confidence Interval]		Unpaired t-test (Ha: Difference ! = 0)
Herd size	Case farm	164	7	0.6	8.0	6	8	0.015
	Control farm	40	11	2.1	13.0	7	15	
	Combined case and control farms	204	8	0.7	9.3	7	9	
	Difference		-4	1.6		-7	-1	
Vaccination per animal (Ksh/animal)	Case farm	41	46	5.3	34.1	35	57	0.829
	Control farm	20	48	6.1	27.4	35	61	
	Combined case and control farms	61	46	4.1	31.9	38	55	
	Difference		-2	8.8		-19	16	
Vaccination per farm (Ksh/farm)	Case farm	41	292	41.7	267.2	208	376	0.022
	Control farm	20	865	340.5	1,522.9	152	1,577	
	Combined case and control farms	61	480	118.4	925.0	243	717	
	Difference		-573	243.2		-1,060	-86	
Cost of concentrates (Ksh/farm/day	Case farm	84	175	18.9	173.5	138	213	0.925
	Control farm	26	179	33.0	168.3	111	247	
	Combined case and control farms	110	176	16.4	171.6	144	209	
	Difference		-4	38.7		-80	73	
Total annual cost of forage	Case farm	67	29,097	5,442.0	44,544.4	18,232	39,963	0.563
	Control farm	19	36,329	13,480.5	58,760.2	8,008	64,651	
	Combined case and control farms	86	30,695	5,150.0	47,759.3	20,455	40,935	
	Difference		-7,232	12,462.2		-2,015	17,550	
Cost of AI	Case farm	93	1,548	102.5	988.8	1,345	1,752	0.516
	Control farm	25	1,684	124.2	620.9	1,428	1,940	

	Combined case and control farms	118	1,577	84.9	922.5	1,409	1,745	
	Difference		-136	208.3		-548	277	
Cost of bull insemination	Case farm	13	342	50.6	182.4	232	453	0.957
	Control farm	2	350	150.0	212.1	-1,556	2,256	
	Combined case and control farms	15	343	46.0	178.2	245	442	
	Difference		-8	140.4		-311	296	
Annual cost of labour (Ksh/farm/year)	Case farm	60	55,400	4,004.3	31,017.3	47,387	63,413	0.033
	Control farm	27	76,667	11,628.1	60,421.6	52,765	100,569	
	Combined case and control farms	87	62,000	4,625.9	43,147.1	52,804	71,196	
	Difference		-1,267	9,789.5		- 40,731	- 1,803	
Annual cost of water (Ksh/farm/year)	Case farm	71	11,001	1,572.8	13,252.8	7,864	14,138	0.551
	Control farm	17	13,239	3,929.8	16,203.0	4,908	21,570	
	Combined case and control farms	88	11,433	1,470.9	13,798.2	8,510	14,357	
	Difference		-2,238	3,739.5		-9,672	5,196	
Amounts of concentrate fed per cow per farm per day	Case farm	84	2	0.1	1.0	2	2	0.926
	Control farm	26	2	0.2	1.0	1	2	
	Combined case and control farms	110	2	0.1	1.0	2	2	
	Difference		0	0.2		0	0	

Appendix 3: Unpaired T-test of continuous variables for indigenous and exotic breed groups of cattle in case farms only in Nakuru County

Variable	Group	No. of Observations	Mean	Standard Error	Standard Deviation	[95% Confidence Interval]		Unpaired t-test (Ha: Difference ! = 0)
Treatment cost	Exotic breeds	29	5,003	1,136.5	6,120.4	2,675	7,332	0.595
	Indigenous breeds	8	3,715	1,969.9	5,571.7	- 943	8,373	

	Combined exotic and indigenous breeds	37	4,725	979.0	5,954.8	2,739	6,710	
	Difference		1,288	2,402.0		-3,588	6,165	
Vaccination per animal	Exotic breeds	13	52	9.1	32.7	33	72	0.323
	Indigenous breeds	7	39	3.8	10.2	30	49	
	Combined exotic and indigenous breeds	20	48	6.1	27.4	35	61	
	Difference		13	12.8		-14	40	
Vaccination per farm	Exotic breeds	13	852	480.3	1,731.7	-194	1,899	0.962
	Indigenous breeds	7	888	438.4	1,160.0	-185	1,961	
	Combined exotic and indigenous breeds	20	865	340.5	1,522.9	152	1,577	
	Difference		- 36	733.5		-1,577	1,505	
Cost of treatment per animal	Exotic breeds	29	2,974	522.8	2,815.5	1,903	4,045	0.075
	Indigenous breeds	8	1,080	448.6	1,268.8	19	2,141	
	Combined exotic and indigenous breeds	37	2,565	438.2	2,665.2	1,676	3,453	
	Difference		1,894	1,030.9		- 199	3,987	
Mortality loss per farm (Ksh/farm)	Exotic breeds	31	9,835	3,752.3	20,892.1	2,172	17,499	0.175
	Indigenous breeds	10	621	600.9	1,900.1	-739	1,980	
	Combined exotic and indigenous breeds	41	7,588	2,897.5	18,553.3	1,732	13,444	
	Difference		9,215	6,672.1		-4,281	22,710	
Mortality loss per animal (Ksh/animal/farm)	Exotic breeds	31	2,142	914.4	5,091.4	274	4,009	0.197
	Indigenous breeds	10	11	10.1	32.1	-12	34	
	Combined exotic and indigenous breeds	41	1,622	703.6	4,505.5	200	3,044	
	Difference		2,131	1,624.0		-1,154	5,416	
Level of milk production before disease (litres /farm)	Exotic breeds	14	12	3.2	12.0	5	19	0.169
	Indigenous breeds	5	4	0.8	1.9	2	6	
	Combined exotic and indigenous breeds	19	10	2.5	10.9	5	15	
	Difference		8	5.5		- 4	19	
Milk production after disease (Litres /farm)	Exotic breeds	14	2	0.6	2.1	1	3	0.636
	Indigenous breeds	5	3	0.8	1.7	0	5	
	Combined exotic and indigenous breeds	19	2	0.5	2.0	1	3	
	Difference		-1	1.1		-3	2	
	Exotic breeds	31	11,275	4,077.6	22,703.0	2,947	19,602	

Cost of milk loss per farm (Ksh/farm)	Indigenous breeds	10	1,890	1,015.8	3,212.4	-408	4,188	0.204
	Combined exotic and indigenous breeds	41	8,986	3,145.0	20,138.0	2,630	15,342	
	Difference		9,385	7,263.1		-5,306	24,076	
Cost of milk loss per animal per farm (Ksh/animal/farm)	Exotic breeds	29	6,440	3,099.8	16,692.7	90	12,790	0.325
	Indigenous breeds	9	831	439.5	1,318.5	-183	1,844	
	Combined exotic and indigenous breeds	38	5,112	2,390.1	14,733.8	269	9,954	
	Difference		5,609	5,622.3		-5,793	17,012	
Milk drop per farm due to LSD (litres/farm)	Exotic breeds	14	10	3.0	11.4	3	16	0.124
	Indigenous breeds	5	2	0.7	1.5	0	3	
	Combined exotic and indigenous breeds	19	8	2.4	10.4	3	13	
	Difference		8	5.2		- 3	19	

Appendix 4: Unpaired T-test of continuous variables for indigenous and exotic breed groups of cattle in case and control farms in Nakuru County

Variable	**Group**	**No. of Observations**	**Mean**	**Standard Error**	**Standard Deviation**	**[95% Confidence Interval]**		**Unpaired t-test (Ha: Difference ! = 0)**
Herd size	Exotic breeds	136	7	0.7	8.3	5	8	0.003
	Indigenous breeds	69	11	1.3	10.6	8	13	
	Combined exotic and indigenous breeds	205	8	0.7	9.3	7	9	
	Difference		- 4	1.3		- 7	- 1	
Vaccination per animal (Ksh/animal)	Exotic breeds	38	50	5.9	36.6	38	62	0.270
	Indigenous breeds	23	41	4.4	21.3	31	50	
	Combined exotic and indigenous breeds	61	46	4.1	31.9	38	55	
	Difference		9	8.4		- 7	26	
Vaccination per farm (Ksh/farm)	Exotic breeds	38	477	169.6	1,045.2	134	821	0.980
	Indigenous breeds	23	484	146.8	704.2	179	788	
	Combined exotic and indigenous breeds	61	480	118.4	925.0	243	717	

	Difference		- 6	246.4		-499	487	
Cost of concent rates (Ksh/fa rm/day	Exotic breeds	106	179	16.9	173.7	146	213	0.362
	Indigenous breeds	4	99	35.6	71.3	-14	212	
	Combined exotic and indigenous breeds	110	176	16.4	171.6	144	209	
	Difference		80	87.4		- 93	253	
Total annual cost of forage	Exotic breeds	46	36,355	8,727.0	59,189.6	18,778	53,932	0.241
	Indigenous breeds	40	24,186	4,603.5	29,114.9	14,875	33,498	
	Combined exotic and indigenous breeds	86	30,695	5,150.0	47,759.3	20,455	40,935	
	Difference		12,169	10,301.3		-8,316	32,654	
Cost of AI insemin ation	Exotic breeds	114	1,592	87.6	935.0	1,419	1,766	0.348
	Indigenous breeds	4	1,150	50.0	100.0	991	1,309	
	Combined exotic and indigenous breeds	118	1,577	84.9	922.5	1,409	1,745	
	Difference		442	469.5		-488	1,372	
Cost of bull insemin ation	Exotic breeds	11	355	51.1	169.5	241	468	0.702
	Indigenous breeds	4	313	112.5	225.0	-46	671	
	Combined exotic and indigenous breeds	15	343	46.0	178.2	245	442	
	Difference		42	107.3		-190	274	
Annual cost of labour (Ksh/fa rm/year)	Exotic breeds	67	65,373	5,637.8	46,147.6	54,117	76,629	0.184
	Indigenous breeds	20	50,700	6,536.2	29,230.7	37,020	64,380	
	Combined exotic and indigenous breeds	87	62,000	4,625.9	43,147.1	52,804	71,196	
	Difference		14,673	10,943.4		-7,085	36,432	
Annual cost of water (Ksh/fa rm/year)	Exotic breeds	77	12,365	1,648.0	14,461.3	9,083	15,648	0.094
	Indigenous breeds	11	4,909	1,108.1	3,675.0	2,440	7,378	
	Combined exotic and indigenous breeds	88	11,433	1,470.9	13,798.2	8,510	14,357	
	Difference		7,456	4,400.5		-1,292	16,204	
Amounts of concent rate fed per cow per farm per day	Exotic breeds	106	2	0.1	1.0	2	2	0.465
	Indigenous breeds	4	2	0.3	0.6	1	2	
	Combined exotic and indigenous breeds	110	2	0.1	1.0	2	2	
	Difference		0	0.5		- 1	1	

Appendix 5: Logistic regression results of some of farm practices in Nakuru County, Kenya

Variable	Variable levels	Cases	Controls	Total	% cases	% controls	% Total	Odds Ratio	Std. Err.	z	P>z	[95%Conf. Interval]	
Relationship status of respondent	Owner*	33	131	164	80.5	79.9	80.0						
	Manager	7	15	22	17.1	9.1	10.7	2.3	1.2	1.5	0.12	0.8	6.5
	Other (Daughter, son or wife of the owner)	1	18	19	2.4	11.0	9.3	0.1	0.2	-1.7	0.09	0.0	1.3
Farms sourcing labour from outside the farm	No*	14	150	164	34.1	91.5	80.0						
	Yes	27	14	41	65.9	8.5	20.0	4.2	1.7	3.6	0	1.9	9.3
Acaricide control of ticks	Spraying at home*	37	159	196	90.2	97.0	95.6						
	Dipping at the community dip	4	5	9	9.8	3.0	4.4	3.7	2.9	1.7	0.10	0.8	17.3
Frequency of acaricide application	Biweekly*	2	4	6	4.9	2.4	2.9						
	Weekly	24	109	133	58.5	66.5	64.9	0.4	0.3	-1.1	0.29	0.1	2.3
	Every two weeks	7	28	35	17.1	17.1	17.1	0.4	0.4	-0.8	0.40	0.1	3.2
	Every three weeks	0	2	2	0.0	1.2	1.0						
	Monthly	6	10	16	14.6	6.1	7.8	1.0	1.1	0.0	0.98	0.1	8.8
	Every two months	2	1	3	4.9	0.6	1.5	3.3	5.2	0.7	0.46	0.1	76.4
	Every three months	0	1	1	0.0	0.6	0.5						
	Rarely	0	5	5	0.0	3.0	2.4						
	Never	0	4	4	0.0	2.4	2.0						
Purpose of introduction of new animals	Bull service	0	1	1	0.0	0.6	5.9						
	Increasing the herd	5	1	15	12.2	0.6	88.2						
	Replacement animal	0	1	1	0.0	0.6	5.9						

Appendix 6: What farmers think are the factors that cause LSD outbreak in the area

Factor	Number of responses from case farms	Number of responses from control farms	Total responses	Percent of responses from case farms	Percent of responses from control farms	Percent of total responses
Unknown	24	84	108	82.8	77.8	78.8
Mixing of affected with unaffected ones along the road	1	5	6	3.4	4.6	4.4
Spread by wind	0	5	5	0.0	4.6	3.6
Biting flies	2	3	5	6.9	2.8	3.6
There was an outbreak in the area	0	3	3	0.0	2.8	2.2
Cows from Loruk in Baringo and Pokot going to Marigat, Mogotio, Nakuru and KMC passing through the area	0	1	1	0.0	0.9	0.7
Drought making the cattle weak	0	1	1	0.0	0.9	0.7
Ticks	0	1	1	0.0	0.9	0.7
May have been caused by Maasai cattle which were grazing around the area	0	1	1	0.0	0.9	0.7
Maybe from the bush	1	0	1	3.4	0.0	0.7
Mixing of cattle with cattle from Narok when grazing on the road	0	1	1	0.0	0.9	0.7
New animal in the farm and movement to the dip	0	1	1	0.0	0.9	0.7
Taking the animal for bull service	0	1	1	0.0	0.9	0.7
The cow must have come with it from the market I bought it from	0	1	1	0.0	0.9	0.7
Vaccinators vaccinating using the same needle from infected herds	1	0	1	3.4	0.0	0.7

Appendix 7: Herd structure and sizes in case and control farms in Nakuru County at individual animal level

Breed	Category	Case farms (n=448)	Control farms (n=1,183)	p-value
Exotic (n=734)	Lactating (n=272)	0.18 (0.14,0.21)	0.16 (0.14, 0.18)	0.57
	Female calves (n=110)	0.07 (0.05,0.10)	0.07 (0.05, 0.08)	0.61
	Male calves (n=68)	0.04 (0.02,0.06)	0.04 (0.03, 0.05)	0.74
	Heifers (n=182)	0.09 (0.06,0.11)	0.12(0.10, 0.14)	0.07
	Dry cows (n=56)	0.03 (0.01,0.04)	0.04 (0.03, 0.05)	0.57
	Bulls (n=46)	0.04 (0.02,0.06)	0.02 (0.01, 0.03)	0.05
Indigenous (n=739)	Lactating (n=189)	0.10 (0.07,0.13)	0.12 (0.10, 0.14)	0.20
	Female calves (n=95)	0.04 (0.03,0.06)	0.06 (0.05, 0.08)	0.19
	Male calves (n=71)	0.05 (0.03,0.07)	0.04 (0.03, 0.05)	0.79
	Heifers (n=174)	0.15 (0.11,0.18)	0.09 (0.07, 0.11)	0.00
	Dry cows (n=107)	0.06 (0.03,0.07)	0.07 (0.05, 0.08)	0.38
	Bulls (n=103)	0.09 (0.06,0.11)	0.05 (0.04, 0.07)	0.02
Farms keeping both Exotic and indigenous cattle breeds (n=158)	Lactating (n=28)	0.01 (0.00,0.02)	0.02 (0.01, 0.03)	0.61
	Female calves (n=19)	0.01 (0.00,0.02)	0.01 (0.01, 0.02)	0.71
	Male calves (n=12)	0.00(-0.00,0.01)	0.01 (0.00, 0.01)	0.61
	Heifers (n=70)	0.03 (0.02,0.05)	0.05 (0.04, 0.06)	0.20
	Dry cows (n=7)	0.00 (0, 0)	0.01 (0.00, 0.01)	0.23
	Bulls (n=22)	0.02 (0.00,0.03)	0.01 (0.01, 0.02)	0.83

Appendix 8: T test results for mean differences for continuous variables associated with cattle management in Nakuru County

Parameter	Case farms	Control farms	p-value
Total cost of vaccination per farm (Ksh) (n=20,41)	865 (152, 1,577)	292 (208, 376)	0.02
Number of animals vaccinated per farm (n=20,41)	15 (7, 23)	7 (5, 9)	0.02
Amount of concentrates fed per animal per day (kg) (n=26,84)	1.20 (1.48, 2.29)	0.95 (1.64, 2.09)	0.25
Daily cost of concentrates per farm (Ksh) (n= 26, 84)	179 (111, 247)	175 (138, 213)	0.93
Monthly cost of forage per farm (Ksh) (n=19,67)	3027 (667, 5,388)	2425 (1,519, 3,330)	0.56
Monthly cost of hired labour per farm (Ksh) (n=27, 60)	6,389 (4,397, 8,381)	4,617 (3949, 5,284)	0.03
Monthly cost of water per farm (Ksh) (n=17,71)	1,103 (409, 1,797)	917 (655, 1,178)	0.55

Cost of bull insemination per farm (Ksh) (n=2,13)	350 (-1,556, 2,256)	342 (232, 453)	0.98
Cost of AI insemination per farm (Ksh) (n=25, 93)	1,684 (1,428, 1,940)	1,548 (1345, 1752)	0.52
Number of animals treated against diseases per farm (n=37, 35)	3 (2, 4)	2 (1, 3)	0.56
Number of animals that died per farm per year (n=8, 8)	3 (1, 5)	3 (0, 5)	0.71
Herd sizes (n=40, 164)	11 (7, 15)	7 (6, 8)	0.02
Cost of treatment of sick cattle (Ksh) (n=37, 25)	4,725 (2,739, 6,710)	2,867(1,921, 3,813)	0.14
Milk production before disease (litres) (n=19, 22)	10 (5, 15)	11 (8, 14)	0.69
Milk production after disease (litres) (n=19, 9)	2 (1, 3)	5 (0, 10)	0.06

Exchange rate: 1USD=101Ksh

Appendix 9: The roles played by family members in cattle production in Nakuru County

Family member	**Activity**	**Case farms**	**Control farms**	**p-value**
Mother (n=18, 119)	Taking cattle to the water place (n=5, 40)	0.28(-0.03,0.27)	0.34 (0.25, 0.42)	0.82
	Cattle herding (n=5, 37)	0.28 (-0.03,0.27)	0.31 (0.23, 0.39)	0.99
	Fetching cattle water (n=3, 9)	0.17(-0.05,0.19)	0.08 (0.03, 0.12)	0.41
	Spraying of cattle (n=3, 33)	0.17(-0.05,0.19)	0.28 (0.20, 0.36)	0.48
	Other activities (n=0, 4)	0 (0)	0.03(0.00,0.07)	0.97
	Cleaning the cattle shed (n=9, 41)	0.50(0.03,0.41)	0.34(0.26,0.43)	0.31
	Fetching grass for the cattle (n=5, 41)	0.28(-0.03,0.27)	0.34(0.26,0.43)	0.77
	Milking (n=14, 101)	0.78(0.12,0.56)	0.85(0.78,0.91)	0.68
	Treatment of uncomplicated conditions (n=1, 9)	0.06(-0.05,0.10)	0.08(0.03,0.12)	1.00
Father (n=18, 83)	Taking cattle to the water place (n=7, 18)	0.39(0.16,0.61)	0.22(0.13,0.31)	0.22
	Cattle herding (n=5, 18)	0.28(0.07, 048)	0.22(0.13,0.31)	0.80
	Fetching cattle water (n=3, 8)	0.17(-0.01,0.34)	0.10(0.03,0.16)	0.65
	Spraying of cattle (n=16,71)	0.89(0.74,1.03)	0.86(0.78,0.93)	1.00
	Cleaning the cattle shed (n=8, 32)	0.44(0.21,0.67)	0.39(0.28,0.49)	0.84
	Fetching grass for the cattle (n=6,33)	0.33(0.12,0.55)	0.40(0.29,0.50)	0.81

	Milking (n=8, 32)	0.44(0.21,0.67)	0.39(0.28,0.49)	0.84
	Cattle treatment (n=2,21)	0.11(-0.03,0.26)	0.25(0.16,0.35)	0.32
Daughter/Girls (n= 11, 37)	Taking cattle to the water place (n=5, 12)	0.45(0.16,0.75)	0.32(0.17,0.48)	0.66
	Cattle herding (n=4, 13)	0.36(0.08,0.65)	0.35(0.20,0.51)	1.00
	Fetching cattle water (n=1, 1)	0.09(-0.08,0.26)	0.03(-0.03,0.08)	0.94
	Spraying of cattle (n=0, 3)	0 (0)	0.08 (-0.01,0.17)	0.79
	Cleaning the cattle shed (n=5, 9)	0.45(0.16, 0.75)	0.24(0.10,0.38)	0.33
	Fetching grass for the cattle (n=2, 8)	0.18(-0.05,0.41)	0.22(0.08,0.35)	1.00
	Milking (n=9, 18)	0.82(0.59,1.05)	0.49(0.33,0.65)	0.11
Son/Boys (n=24, 82)	Taking cattle to the water place (n=10, 32)	0.42(0.22,0.61)	0.39(0.28,0.50)	1.00
	Cattle herding (n=14, 43)	0.58(0.39,0.78)	0.52(0.42,0.63)	0.78
	Fetching cattle water (n=5, 4)	0.21(0.05,0.37)	0.05(0.00,0.10)	0.04
	Spraying of cattle (n=13, 40)	0.54(0.34,0.74)	0.49(0.38,0.60)	0.82
	Cleaning the cattle shed (n=10, 24)	0.42(0.22,0.61)	0.29(0.19,0.39)	0.37
	Fetching grass for the cattle (n=7, 19)	0.29(0.11,0.47)	0.23(0.14,0.32)	0.74
	Milking (n=13, 29)	0.54(0.34,0.74)	0.35(0.25,0.46)	0.16
	Cattle treatment (n=0, 7)	0(0)	0.09(0.02,0.15)	0.31

Appendix 10: Market prices of cattle, cattle products and cost of some inputs in Nakuru County

Parameter description	***Parameters***	***Value***	***Source***
Cost of cattle production	Cost of feed and management (Ksh/farm/month)	18,722	Household survey
Salvage value of meat	Value of meat (Ksh/animal)	2,405	Household survey
Cattle hides (Ksh/kg)	Value of hides grade 1 to 3	25[a] 38[b]	[a]SCVO reports [b]Slaughterhouse/slabs survey
	Value of hides grade 4	15	SCVO reports
	Value of hides rejected hides (e.g. LSD affected hide)	10	Slaughterhouse/slabs survey
Direct costs for control of LSD (Ksh)	Treatment cost per animal	2562	Household survey
	Vaccination cost per animal	46	Household survey
Market prices for indigenous cattle (Ksh)	Cows	15,066	Livestock market survey
	Heifers	18,562	Livestock market survey
	Calves	2,000	Livestock market survey
	Bulls	15,676	Livestock market survey
Market prices for exotic cattle (Ksh)	Cows	70,000	Farm survey
	Heifers	70,000	Farm survey
	Female calves	5000	Farm survey
	Male calves	3,500	Farm survey
	Bulls	30,000	Farm survey
Market prices for cattle products and inputs	Milk (Sh/litre)	36	Household survey
	Beef (Sh/kg)	400	Butchery survey
	Dairymeal (Sh/kg)	33	Agrovets survey

Exchange rate: 1USD=101Ksh